The Development of Soil Survey and Field Pedology in Australia, 1927–67

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Commonwealth Scientific and Industrial Research Organization, Australia
1970

Printed by CSIRO, Melbourne

FOREWORD

Mr. J. K. Taylor was appointed to the CSIRO Division of Soils in 1927 and became Chief of that Division in 1947. He retired from that position at the end of 1963. His period of office coincided with the major period of the development of soil surveys and their widespread application throughout the world. With his predecessor, Professor J. A. Prescott, he was largely responsible for building up the soil surveys in CSIRO and his influence on such endeavours throughout Australia was considerable. He initiated the activity which culminated in the "Atlas of Australian Soils" completed in 1969.

In this review of the development of soil surveys and field pedology in Australia Mr. Taylor presents his own views and interpretation of the course and nature of these activities and his evaluation of the many approaches adopted in this field of agricultural science in this country. The subjects of soil survey and pedogenesis have aroused considerable controversy throughout the years. Mr. Taylor's career fits him well for making such a review which will undoubtedly be of considerable historical significance and value to all students of the subject.

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THE DEVELOPMENT OF SOIL SURVEY AND FIELD PEDOLOGY IN AUSTRALIA, 1927-67

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I. INTRODUCTION

Soil survey, involving soil classification and related to land classification, has developed in a number of countries to a variable degree and is still widely practised. The emphasis placed on it and the detail sought on the soils also varied considerably from country to country and Australia, coming actively into this field 40 years ago, has itself been through a period of changing activity and viewpoint. In the past the opening up of new countries was perforce initially based on the judgment of pioneers until sufficient information had been gathered by hard experience. In Australia this led to a system of land classification by the State Departments of Lands, which undertook to provide data as a direction for settlement.

Traditionally in this country, classification of land for agricultural use was in the province of the State Lands authorities and in some parts of Australia this is still assumed as their prerogative. However, since the beginning of this century agricultural bodies have been concerned increasingly with the soil factor in production, and soil survey investigations have developed extensively.

Land classification relied heavily on the appearance of the surface soil, on the environment (mainly vegetation) and, perhaps to a lesser extent, on geology; by contrast the soil survey placed prime emphasis on the profile of the soil itself. Today environment, including more specifically climate generally and microclimate, is increasingly used as an important guide to land use.

The purpose of this review is to follow the development and achievements of surveys, to examine the methods used and the changing viewpoint of soil surveying in Australia over the period of active work from 1927 to 1967, to set out the accompanying rise of studies in field pedology, and, finally, to consider some possible future trends.

Early Soil Investigations in Australia

Soil investigations in Australia, carried out principally by chemists and geologists, date back to last century. The evaluation of European soils had long been the duty of chemists and soil analysis was assumed to supply reasons for potential productivity or infertility. On the field side the geologist was naturally drawn in by the assumption that the nature and composition of soils were attributable to parent rock material.

Not a great deal was done in Australia, however, until the agricultural aspect came into consideration. Previously a few papers were published, such as J.B. Henson's (1887) discussion of the "healthy" and "unhealthy" soils of Sydney according to their origin, parent material, and mode of formation. T.W.E. David (1887) first described and theorized on laterite as a derivative of volcanic rocks in the

New England district of New South Wales. Botanists concerned with soil drift and conservation, such as Maiden (1903), dealt with ecology and soils. Then came the long series of publications in New South Wales between 1898 and 1922 resulting from the association of F.B. Guthrie and H.I. Jensen of the Department of Agriculture. Masses of analytical data, largely from samples sent by farmers, were put on record by the Departments of Agriculture in New South Wales and Queensland.

Although the United States Soil Survey was known (Guthrie discussed it favourably as early as 1903), there was no move to follow the principles Whitney and his co-workers were establishing by laborious effort in the United States. The first surveys by Jensen covered widely spread parts of New South Wales conducted with sketchy field work. It has to be remembered that transport facilities were limited but it is also true that these field studies were inadequate for the conclusions. Soils were described in the field with specific regard to their assumed parent rocks and characterized through laboratory analyses by the then standard procedures. The investigations ranged over much of eastern New South Wales, culminating in Jensen's 1914 book, "The Soils of New South Wales", which included a generalized soil map. Later work extended into Queensland (Jensen 1922). There were also several earlier papers discussing quality of soils such as that on the Murrumbidgee Irrigation Area prior to settlement (Guthrie 1910). In this and in other papers in the series he included with the chemical analyses the mechanical analyses and an estimate of the water-holding capacity of the soils as a physical criterion.

In all this work there were some incorrect assumptions on the geological and ecological correlations of the soils examined. The field work appears to have been not nearly complete enough even for the type of survey made, and the isolated and "average" samples used for analysis were inadequate for typifying the soils, quite apart from the value of the methods employed. There were many optimistic guesses made on limited evidence, while analytical data were often variable and not as informative as thought at the time. The greatest deficiency was that consideration was given largely to the surface soil layer, particularly to its chemistry and presumed geological parent material. Despite its inadequacies we should recognize the significance of the work in this new field of investigation, where virtually nothing was known. In these circumstances any attack by defined principles is profitable when enough data are accumulated.

It is a sobering thought to all soil scientists that the development of Australian virgin lands by pioneers was frequently successful through recognition of surface features of the soils and their associated vegetation long before any soil surveyor came on the scene. Admittedly in the first place it was by guess and by trial and error, which in some cases undoubtedly was costly, but progress was made in spite of all the mistakes in selection. Further, some of the observations and records of the land surveyors of more than 50 years ago have been found remarkably significant against conclusions obtained by modern surveys. The records of the classification of the Riverine Plain in New South Wales in the 1900-20 period agree reasonably with the soil survey findings 20 and more years later, although, of course, they were less detailed and precise.

Although nothing practical was done except in New South Wales, discussions on soil survey took place in the broader field. A sub-committee of the Advisory Council for Science and Industry reported very positively in 1916 on the need for soil survey and preliminary steps towards it. It stated, "The principle objects of a soil survey are to collect such scientific information with regard to the soils of a country as will permit and encourage settlement upon areas not yet occupied or will lead to an increased yield of produce from lands already settled".

The committee could not envisage any establishment comparable to the United States Soil Survey but saw the advantages of working towards it in a modified form, taking account of surveys in other countries. It stressed the large amount of unpublished data in records of the Departments of Lands, Agriculture, and Geological Survey in the various States and the desirability of attempting to correlate these as a nucleus for development. However, it was stated that it was essential that the control of such work should be central for uniformity and method, and therefore any appointments should be subject to a competent committee of the Advisory Council.

No further steps were taken because of World War I, but the subject was revived by the Australian National Research Council in 1922. A new Committee was nominated under the chairmanship of Professor R.D. Watt, who had all along been a strong supporter of soil survey; F.B. Guthrie continued to be active as on the earlier committee. The five principal resolutions of the Committee were:

"That, in the best interests of land settlement and rural development, it is highly desirable that a start should be made with a systematic soil survey of Australia.

"That attention should first be given to those areas already utilized for agriculture or suitable for closer settlement.

"That, as a large amount of information already exists in the records of the Lands, Agriculture, Geological, and other Departments of the various States, much of which has not been made public, the first step which should be taken is to ascertain as accurately as possible what data are already available for soil survey.

"That this preliminary investigation could be best carried out by the Institute of Science and Industry which should appoint a man to visit the various State capitals to collect information.

"That, when all the available information has been collected, a uniform plan of recording the results of the soil surveys should be adopted by all the States."

The last of these followed a suggestion of the previous Committee that the "final presentation of the data thus collected would be in the form of soil maps of the States specially prepared to contain the information collected, accompanied by such notes in book form as could not readily be included on the maps ...(These maps) could be directly combined so as to form complete presentation of (soil) conditions throughout Australia".

The idea of a national soil survey of Australia was stirring 50 years ago. The concept was correct and remarkably broad. It only failed to be put into practice because of post-war pressures on Australia, the States' preoccupation with land settlement, and a complete lack of properly trained scientists. When soil survey was initiated in its present form some years later on a Federal scale under the Council for Scientific and Industrial Research it began in the opposite way, setting aside Departmental records of the past and making soil maps with new field work to build the present vast mass of soil data concerning, in one way or another, the whole continent.

A few other soil surveys of limited areas, using essentially the same techniques, were carried on in this period up to 1927 (Davies 1917; Teale 1918; Jacobs 1926). It was finally Professor J.A. Prescott who sounded a new note. Prescott (1926) set out for Australian soil workers, in orderly fashion, the four bases used for soil classification: the geological, as used in Britain; the climatic, as evolved by the Russian School in the latter part of the nineteenth century; the ecological, as commonly followed by Australian land surveyors; and the physical, as developed by the United States Soil Survey. All these will later come into consideration of the evolution of the Australian soil survey. The soil was now first viewed as a profile entity with constituent A, B, and C horizons and the depth and character of each horizon were physically as well as chemically emphasized.

There had been calls earlier for extensive surveys, such as that by Cambage (1925), but the first organized soil survey arose from the recommendation of a committee (J.A. Prescott, R.D. Watt, and H. East) appointed by the Council for Scientific and Industrial Research in 1926. Serious problems of deterioration by waterlogging and salinity had been widely recognized in the irrigated lands of the Murray valley and it was proposed by the Committee that a soil survey be made of these areas as the basis for further study. The first of these surveys was carried out at Renmark, South Australia, in 1927 by J.K. Taylor, appointed by CSIR specifically as the first soil surveyor in the Commonwealth. From this small beginning arose an increasingly wide programme of soil surveys extending throughout the Commonwealth.

There cannot be any sharp demarcation between the historical stages of Australian soil survey. A practical date for ending the first period is 1940, partly because World War II caused a decline in activity and partly because a change in techniques was coming. The second stage is arbitrarily closed in 1955, as by this time the demand for soil surveys by Government agencies in connection with post-war land settlement had more or less ceased, while criticism of soil classification had become a major issue among pedologists. The third and current stage is still in evolution.

II. THE FIRST STAGE, 1927-40

The basic principles of the first group of soil surveys were drawn from the methods and usage of the United States Soil Survey, somewhat modified in application to intensively developed irrigation areas. The initial classification and mapping, using the detailed morphology of the soil profile as the basis for definition of soil types, was on the Renmark survey in 1927-28 (Taylor and England 1929). It served as a pattern for the long succession of surveys of the irrigated lands in the Murray and Murrumbidgee valleys for the next 15 years. There is no doubt that this early classification, while firmly based on the whole profile, made use of a synthesis of soil and environment in its application to mapping. Soil types were defined on physical profile morphology, parent material, crop response, microrelief, and approximate field assessments of the permeability of key horizons controlling internal drainage. They resulted from a combination of factual observations and intelligent judgments, from which the soil surveyor decided his mapping units. This is one reason why later critics described soil survey as an art and not a science.

There was a massive accumulation of detailed data, both field and laboratory, on the soils, on their field pattern, and on their inferred plant relations. From this information their productive capacity, fertilizer requirements, and suitability for specific crops were estimated, often with considerable, if not mathematical, accuracy. Since a large proportion of the surveys dealt with irrigation areas the physical state of the soil profile became of overriding importance, although the accumulation of observations was not backed by the kind of experimental data which would now be desired. On the other hand, this first period of surveying saw meticulous recording of soil and crop features which gave the work a value still recognized today in the irrigation areas. The old soil types stand and are used as a workable classification in practice. Indeed, intensive surveys today of new areas in the Murray region would probably seek to employ many of the same units, even if the approach to the survey happened to be in a different form.

The soil series, type, and phase system of the United States Department of Agriculture Soil Survey was adopted with a leaning to monotypic series. There was then a strong suspicion of the value of a multiplicity of units, such as were created for example in the late 'thirties by the United States Soil Conservation Service in its highly detailed mapping. Attempts were always made to keep the number of types down, even if thereby they were made broader. This principle, with a few exceptions, has been followed to the present time. The first survey at Renmark, South Australia, of 3300 acres was mapped in eight types within four series and the adjacent Berri-Cobdogla area of 20,000 acres in 13 types within eight series. The division of the kind of soils spectrum frequently found in the plain deposits of alluvial terraces of the rivers or in the soil catena of the undulating, aeolian landscape of the highland mallee areas of the Murray valley, is often arbitrary. The original decision to widen the permissible textural variation in a specific type has presented a simple soil picture which proved useful in a practical sense for land use. The Australian use of the soil series has always been more flexible than the American concept.

The plan of the survey was simply to traverse the area being studied, using a prismatic compass or subdivisional lines or natural features, at varied, but often fixed, intervals; in the irrigated horticultural land these were as little as 100 yd. Frequent borings with a 4 in. post hole auger usually 40-100 yd apart were made along the traverses to a depth of 3-6 ft. It was early decided that 6 ft should be arbitrarily set as the general working depth for definition of profiles, partly for convenience with the auger but also because it reasonably covered the rooting zone of most plants and was likely to represent the solum, reaching either parent material or significant underlying sediments. Every spot was noted in the field book in detail as to profile description and environment, since landscape features and crop condition or native vegetation were used in the drawing of soil boundaries.

Colour and texture codes were drawn up by J.K. Taylor during the early surveys, initially from field experience and accumulated mechanical analyses of soil samples. A triangular texture diagram showing textural classes in terms of sand, silt, and clay percentages was evolved. This differed from the American diagram which, based on the Atterberg size fractions, used an upper size limit for silt of 0.05 mm instead of 0.02 mm. These texture classes and their particle size ranges have largely stood, as far as Australian practice is concerned, to the present day. They were confirmed by more detailed correlation of mechanical analyses and field texture assessment (Prescott, Taylor, and Marshall 1934) and shown in a new form on a rectangular diagram by Marshall (1947). Taylor (1943) defined the colour classes used in the field with a colour-measuring device of four Munsell disks - black, white, yellow, and red - spun as combinations in different proportions. The descriptive colours today are much the same but the Munsell colour charts, introduced from America for general practice in 1956, give much more precision to colour definition. Colour was then stated, following American practice, on the dry soil.

Much of the early work was on planted and irrigated land from which a fund of knowledge was built up, later to be extrapolated to virgin land for estimating potential plant response, more or less hypothetically, but with a good measure of success. In the detailed surveys the frequency of observations and the use of aerial photographs allowed a simple lining in of boundaries. It may be noted that aerial photographs were used for this as early as 1928 (Prescott and Taylor 1930) before their value for soil survey purposes was properly recognized in any other country. From that date, the very great bulk of Australian soil surveying has been accompanied by interpretation of aerial photographs. Subsequent, and particularly recent, experience has made them very much more useful still. It should be emphasized again that the salvation of these early surveys lay in intensive and skilful observation, as they were not aided by the studies of the genetics of the soils or of landforms, which came later. It is perhaps significant that almost all the early soil surveyors were trained in agriculture and viewed the soils as a problem factor in agricultural production so that interpretations of the soils were coloured in this way rather than by, say, geomorphology.

While a standard system of soil surveying was developing in the irrigated areas a number of surveys of both detailed and broader type were carried out in the rainfall areas in southern Australia. The description and separation of soil types and the techniques of surveying were on the same lines, modified to suit the definition of appropriately flexible units for reconnaissance work. Some of the mapping units in the broad-scale surveys were considerably broader than soil series.

The total areas involved in soil surveys in the 1927-40 period are shown in Table 1. The figures are dominated by Western Australian surveys, but this should not reduce the significance of the other work especially considering the relatively small number of surveyors engaged on them, in all fewer than 10, through this period.

TABLE 1

Areas involved in Soil Surveys, 1927-40

State	Units Surveyed	Detailed Surveys		Broad-scale Surveys (sq miles)
		Irrigation (ac)	Non-irrigation (ac)	
South Australia	8	51,000	111,000	360
Victoria	8	95,000	50,000	-
New South Wales	3	41,000	-	-
Western Australia	9	-	1,226,000	6,500
Tasmania	3	-	20,000	438
	31	187,000	1,407,000	7,298

It should be recognized that particularly in the first decade of surveying, each new area was a research study in itself due to the considerable variety of problems and types of country involved, often over widely scattered regions. The only surveys which had any continuity in objective and in the character of the country were those in the Murray valley and in the Western Australian wheat belt. Against this the riverine and mallee soils are extremely variable and raised problems in classification and mapping. The picture has become clearer with progress in the study of field pedology. It was on the soundness of the early work, which included a wide array of surveys with diverse objectives, that their popular reputation was built, so that in the post-war years, a confident demand for a wide extension of them was made by Government agencies.

It is interesting to note the background and nature of a few of these surveys. The Renmark survey and those which followed in the Murray valley were instigated by State authorities following the deterioration of the lands under irrigation and the necessity to seek both means of reclamation and a basis to work on in any future development. The surveys extended and intensified knowledge of the river flat lands and adjacent mallee highlands devoted to horticulture. The picture of this as far as irrigation settlements were concerned was largely complete by 1940 from Tresco in Victoria to Cadell in South Australia. The post-World War II settlements in the Murray valley were built on this established relation of soil types to crops and their irrigation requirements and to their need for, and design of, drainage systems.

A unique investigation in the Murray valley was carried out at the request of the South Australian Parliamentary Committee on Public Works on the flooded bed of Lake Albert near the mouth of the Murray river. (Taylor and Poole 1931). The successful reclamation of the swamp lands of high fertility along the lower river (Taylor and Marshall 1931) had led to a theory, on quite optimistic grounds, that the black mud beneath Lake Albert was equally good. The mud bottom was sampled, where possible, to a maximum depth of 14 ft with a modified Frankel-type sampler. In summary, the finding was disappointing as the lake mud, although naturally fertile, overlay at depths of less than 6 ft sand or sheet limestone for 55% of the area and the clay was of a particularly colloidal nature with a high shrinkage value on drying. It was also highly saline and would be extremely difficult to reclaim agriculturally.

The large-scale surveys with both detailed and broad mapping units should be mentioned and specifically three cases - the surveys in the wheat belt of Western Australia, on King Island, Tasmania, and in the Hundreds of Laffer and Willalooka, South Australia.

The wheat belt surveys in Western Australia date from proposals advanced for the settlement of English migrants under what was popularly called the 3500 Farms Scheme. The Australian Government had co-operated with the British Government in post-World War I migration to Australia by setting up the Development and Migration Commission. The Commission considered the Western Australian proposal, which was to open up wheat farms in the Salmon Gums-Newdegate district, where a very limited amount of development had previously taken place. In view of the high cost and human risk involved, a reconnaissance survey was run by L.J.H. Teakle on 4 million acres to define the soils in the broad groups used by State land classifiers, e.g. first-class woodlands, which were considered the most useful soils, or sandy, gravelly soils of higher plain areas, rated as unusable. Special attention was paid to the salinity problem.

The salinity and soil surveys in the Salmon Gums and other dry districts in Western Australia between 1930 and 1935 (Teakle 1939; Teakle, Southern, and Stokes 1940) were the work in particular of L.J.H. Teakle, G.H. Burvill, and L.W. Samuel. The surveys used essentially the grid of compass traverses and soil type definition as previously described for the irrigation areas. It involved tremendous effort to examine over 5 million acres. The work, partly in moderate detail, partly in reconnaissance, was an attempt to define tracts suitable for arable farming in a 12-14 in. rainfall zone and under conditions complicated by a salinity problem. The initial reconnaissance survey clearly showed the relation of soil salinity to land use, so that subsequently the work turned on an understanding of the relation of the mapped soil types to salt status under virgin and cultivated conditions. The conclusions reached on the potential usefulness of the "light land" with a sandy surface over permeable finer-textured or calcareous horizons have since been widely applied in Western Australia, and modified as later research in trace element deficiencies and improved management practice enabled partial use of some low-fertility and more saline soils.

This survey was very important, firstly, in showing the value of soil survey of virgin land for pre-settlement investigations, secondly, in setting out the problems, particularly salinity, governing development in the lower-rainfall wheat belt, and thirdly, as being the forerunner of the extensive field work carried on over the next 5 years which largely provided the basis for agricultural evaluation of these regions. The soil maps have had a continuing value and no extensive surveys were made on this class of country for the next 30 years (see Section V). It should be added that the field technique, effective as it was, would not be used in present-day surveys.

King Island, Tasmania, (Stephens and Hosking 1932) was covered in reconnaissance as a basis for attack on problems in animal health, such as coast disease. Pastoral development was hindered by these although climatic conditions were very favourable. The problem though not then solved was put in sharp focus by the survey which in the next 10 years proved invaluable for the application of research in trace element deficiencies. The accessibility of the major part of the island was very poor and the field work arduous by any standards.

The survey of the Hundreds of Laffer and Willalooka in the upper South-east of South Australia was undertaken at the request of the State Government to determine the nature and problems of the soils for possible development to cereal cropping. The whole area was covered by dense low mallee, dwarf woody shrubs, and saline flats and used for rough grazing by sheep at very low rates. Compass traverses were run at about three-quarter mile intervals with much interpolative sketching in of soil boundaries, based on relief and vegetation.

In both these surveys ecology and geomorphology were freely used in the mapping. Both were basically geographic exercises, defining rather broad units in landscapes, whatever they were called. They were not in fact soil series in most cases. For their objective of estimating potential land use, on the existing state of knowledge of fertility, they served well enough until later surveys more precisely fixed the soil patterns.

It may not always be realized that some early surveys, such as the three mentioned, entailed a degree of hardship and effort much removed from that in present work, except in desert areas and in New Guinea. The mobility attained with modern transport, progress in aerial photography and photo-interpretation, spread of experimental development by land-holders, and advances in scientific knowledge make surveys and assessments easier. Re-surveys always have these advantages and may therefore present different pictures from the originals in detail.

In the late 1930s increasing attention was being paid to the low-fertility, high-rainfall soils with trace element deficiencies, although not all of these latter were recognized. The surveys at Gin Gin and Denmark in Western Australia were essentially based on such fertility studies in an attempt to improve animal health, grazing potential of pastures, and crop response on different soils thought to have greater than the then current values. Although these problems were certainly not all solved, the surveys provided the basis for later experiment and a field understanding of their results. The areas were representative of extensive parts of the coastal sandy plain and of the lateritic landscape generally found in the south-western region of Western Australia.

Naturally there were defects in the early survey work, more clearly seen after 30 years. The introduction of geomorphology and the recognition of buried ground surfaces, for example, have led to different views on the occurrence and genesis of some soils. It would indeed be unfortunate if we were tied inflexibly to methods of survey and classification, preventing new ideas from assisting interpretation of soils and problems in the field. However, this period to 1940 was the time when sound foundations at least were laid and soil surveys established as useful, even necessary, preludes to settlement and for the solution of many agricultural problems. It was only a beginning, but a worthy one.

Salinity Surveys

The salinity survey, which was always associated with soil mapping, had a vogue only during the 1930s, although some has been done in more recent years. Salinity in the root zone of plants in the virgin state is not significant under irrigation except by close correlation with the soil profile and the potential rise of ground water to within 6 ft from the surface. Salinity maps are at best an approximation to show the general distribution of soluble salts and the relation of the soil type to salt accumulation.

The wheat belt surveys in Western Australia mentioned above showed the position in low-rainfall virgin land; for irrigated soils the Nyah-Tresco, Victoria, survey (Taylor *et al.* 1933) and the Kerang, Victoria, survey (Baldwin, Burvill, and Freedman 1939) attempted to delineate intensity of salt occurrence in already badly affected areas. A recent salt survey of the former area (Skene and Sergeant 1966) produced much the same conclusions but, understandably, a quite different map. Salt status under the effects of irrigation or seepage is never constant, so that any detailed definition of broad areas is unsatisfactory. It can, of course, be defined at a given time on restricted or farm size units. The best attempt at intensive salt mapping over a large area was the Kerang, Victoria, survey (*loc. cit.*). It is very doubtful if salinity mapping in detail would be undertaken now over extensive areas and it would certainly not be an economic practice except, possibly, in specific local cases for drainage or reclamation.

In these surveys, to minimize effort in dealing with large numbers of sites, it was decided to assess profile salinity on a single sample, with suitable checks, taken at a depth of 2 ft. For convenience the estimation was of sodium chloride, which constitutes 60-80% of the total soluble salt content where this reaches significant levels in the Murray valley. The fluctuation of salt content before and after irrigation is reduced to a reasonably small range using the 2 ft sample. The selected depth is naturally dependent on the soil profile and ground water movement and varies between irrigated and dry areas.

Laboratory Analysis

Efforts were always made to establish the identity of the surveyors' soil types by standard analyses, in particular using mechanical analysis, pH, soluble salt content, carbonates, total nitrogen, phosphorus, and potassium; on a strictly limited number of samples exchangeable cations were determined. Now in fact, the number of profiles of each soil type selected in any one survey was always small, rarely more than three and, for less important types, only one. There was also an assumption that they were suitably representative. As realized later, the number of type profiles was too few to characterize the soil units. Between their assumed typicality and the practicability of handling analyses, the system of examination in the laboratory was standardized as a routine for the characterization of the soils. However, on the irrigation areas in the Murray valley, so important in the period to 1940, the analytical data were frequently of less significance to the surveyor once the general nature of the soils had been established. For example, all soils from an irrigated mallee highland in the Murray valley showed considerable deficiencies in phosphorus and nitrogen, an adequacy of potassium, an alkaline trend through the profile, an increase of salinity with depth, and a rise in exchangeable sodium and magnesium in lower horizons, while the mechanical analysis, in general, confirmed field estimates of texture. The surveyors developed considerable skill in deciding field textures and in estimating the particle size analysis approximately, although obviously not precisely. However, the occurrence of subplastic clays in the soils of the riverine plains of south-western New South Wales (Taylor and Hooper 1938) troubled the surveyors with their apparent light texture, strong development of structure, and high permeability. This was the first record in Australia of subplastic clays with a very high clay content but with a field texture of no more than a clay loam.

The surveyors were constantly asking the chemists what confirmatory evidence could be found for distinguishing the soil types considered morphologically distinct in the field. This was the period when all reliance was placed on soil chemistry, as soil mineralogy was not thought of, spectrographic analysis had not begun, and soil physics was in an elementary state of development. Very few chemists seemed able to project themselves into the field worker's problems, which standard soil analyses were not adequately answering. Twenty years later, the standard analyses had been greatly reduced and refinements of these with new techniques, physical and chemical, were used more selectively for characterizing the soils.

The case was quite different for the broader surveys and the reconnaissance surveys in rainfall areas where a wide range of soils of distinctive character and varying derivation and genesis was involved. For these soils the standard analytical tests were of clear value and chemical and physical work was essential to back up the surveyors' opinion.

III. THE DEVELOPING YEARS, 1940-55

The second stage was one of expansion and experimentation in soil survey during which it was brought to its greatest development and achieved wide public recognition. Soil survey moved away from the dominance of detailed work according to the principles used in the irrigated horticultural areas, into a wide range of mapping up to the level of the broadest reconnaissance. The early advances were on large irrigation areas in south-western New South Wales and central Victoria, which were devoted to grazing and limited cereal-cropping. Obviously the precision sought for high-value land already planted to horticultural crops did not need to apply to large grazing units of 500 ac or more, irrigated over only 10 or 20% of their area. The pattern of the soils and the inter-association of soil types were more important and the idea of the soil association was conceived. It was first used in the survey of County Moira, Victoria, (Butler *et al.* 1942) to delineate a group of soil types found in a recurring pattern and including one or more dominant types with lesser associates. The same general concept of a soil association had been used previously by the United States Soil Survey, though as a different approach and apparently not as a field mapping unit (United States Department of Agriculture 1938). This is the equivalent of the botanists' vegetation association.

The procedure was to select small areas of 100-500 ac typifying representative landscapes with characteristic topography, vegetation, microrelief, and surface drainage, and to carry out detailed surveys on them. From these was defined the array of soil types likely to be encountered in similar areas in the whole survey project and thus the common associations of soil types were formulated. These could be recognized in the landscape along the lines of traverse and the whole area could then be mapped rapidly, in fact at about ten times the speed of the earlier detailed surveys. They were detailed surveys actually, as it was still necessary to define the individual soil types, though without mapping them over the whole area, so that if more information was needed on farm units, a basic classification of the soils would be available. The soil types were characterized in the laboratory as far as possible on samples from sites in the "spot surveys".

Soil association mapping on these principles, using units from soil types to great soil groups, continued vigorously over many areas of southern and eastern Australia until the late 1950s and is still practised on a reduced scale. Soon after its initial use it was applied to rainfall country and it was in this form that surveys were sought by Governments for post-war land settlement after 1945. The same techniques were used as on the irrigation areas though the thoroughness of the "spot survey" tended to become less and under some circumstances it was not used at all, according to the skill of the surveyor. At the extreme, great soil groups were used as the units and mapped in "combinations", e.g. in the Macquarie region, New South Wales, survey (Downes and Sleeman 1955). This last was a plain reconnaissance of soil resources over an extensive area and had nothing to do with applied land use. It was the first *reconnaissance* survey of a large regional area dealing primarily with soils and only on relatively few occasions has this been repeated (e.g. in central Australia, Jackson 1962). The mere mapping of soils over an arable farming region as associations, or as the wider combinations, of great soil groups has severe limitations of usefulness and the recognition of this fact prevented much replication of such surveys except in an academic way.

Surveys, of course, still continued on the soil-type basis, notable examples being the surveys of part of the South-east of South Australia (Stephens *et al.* 1941) and of County Victoria, South Australia (Stephens *et al.* 1944). It is probable that in these and later surveys of this type the soil series was a broader and more flexible unit. Australian field work has the merit of individuality, and there has never been a rigid, standard system imposed to which surveyors were obliged to conform as in the United States Soil Survey. It has led to flexibility and experiment in survey systems and techniques, which is the quickest way to progress, but there is therefore no simple chronological line of development to be seen.

The very great advance in soil surveys during the 1940-55 stage (Table 2) may be seen by comparison with the areas in Table 1, which, if the large surveys in Western Australia are excluded, appear small by comparison. The number of surveyors active in the period rarely exceeded 20 in any one year for the whole of Australia.

TABLE 2

Areas covered by Soil Surveys, 1940-55

State	Detailed Surveys		Broad-scale Surveys	Reconnaissance Surveys
	Irrigation (ac)	Rainfall (ac)	(sq miles)	(sq miles)
South Australia	29,000	2,761,000	4,155	51,000
Victoria	683,000	529,000	2,942	-
New South Wales	1,676,000	1,047,000	2,274	25,000
Queensland	3,000	104,000	8,912	1,125
Tasmania	-	889,000	1,621	-
Western Australia	-		4,517	-
North Australia			15	322,300*
Total	2,561,000	5,831,000	24,781	399,425

*This area in northern Australia is made up from resources surveys by the CSIRO Division of Land Research which include field data on the soils but are not basically soil surveys.

It should be understood that the term"detailed" applied to non-irrigated soils is relative, as rarely would the same intensity of mapping and observation be entailed as for the irrigated areas. The word means that classification involved a definition of soil types and, even where soil association mapping only was done, a considerable amount of data on the individual soils and their distribution was assembled which was directly applicable to land use. The "reconnaissance" is an assessment of the soils in broad form with the use, for example, of great soil groups or subgroups as units in the associations. The tendency as time went on was to do less close detailed work and, in the soil association itself, to use broader and more flexible classification units.

The soil survey then was at its peak of activity in the post-war decade. There was an unprecedented exploration of soil resources within the better rainfall limits, always accompanied by agronomic investigation of deficiency problems and production of new varieties of plants suited to regions with near-marginal conditions. The move is still going on with the tremendous advances in opening up low-fertility areas in Western Australia and the brigalow belt of Queensland, but the foundation for all this goes back to the golden age of soil surveying in the post-World War II period.

In the 10 years from 1945 the soils of whole regions, particularly in southern Australia, were surveyed in some degree of detail, new ideas in mapping were put into practice, and experiments made with new approaches. Crown lands, being the major areas available for post-war land settlement, were examined for potential development. They had not previously been opened, despite favourable rainfall, because of infertility through soil deficiencies. The surveys provided the basis for agronomic and fertility studies. New irrigation areas were vigorously sought in the Murray River region; at least 30,000 ac of new horticultural land was planted and much more was soil surveyed prospectively. Altogether a vast body of knowledge was built up on Australian soils and their problems to allow development of the land.

Australian soils on the basis of natural fertility and moisture regimes are the poorest continental land areas in the world. To make them produce highly, and in many cases to produce agriculturally at all, means close study and experimentation. The practice of soil survey not only produced the soil maps but gave the surveyors an intimate knowledge of the soils possessed at the time by no other agricultural worker. Indeed, without the surveys the basis for research and progress in development would have been lacking, as for example, on the lateritic formation of central Kangaroo Island, South Australia (Northcote and Tucker 1948). Nothing could have taken the place of these surveys for understanding the soils and their problems. The surveyor, through his observation in field mapping, gets very close to them, seeing the same soil type, the same associated vegetation or crop, in the same landscape, not as a casual traveller, but living with them daily, often for months. There may be better ways and better survey methods for understanding soils, but the techniques used then served their purpose well.

It was in this period that the soils of 3 million acres of the Riverine Plain of southern New South Wales and northern Victoria were mapped and their potential problems defined, if water were applied. Irrigation districts, existing in name only as areas commandable by gravity flow from the Murray River in New South Wales and in the dry state having a low grazing efficiency of one sheep to 3 or 4 acres, were soil surveyed as a prelude to closer settlement. Deniboota, Jernargo, Murrakool, Denimein, Billabidgee, and other lesser units, totalling more than one million acres, were mapped and the soils given an irrigability classification. Two earlier surveys - the Wakool and Berriquin Irrigation Districts - covering over one million acres and only partially settled were done in the early 1940s in some degree of detail. They provided a useful basis for classification of the soils, only the best of which could be irrigated due to the limitation on farm water rights. The picture built up on the soils of the Riverine Plain was invaluable both for later land use and for the understanding of the pedology and problems of the soil formations (see Section VII). There is not yet any substitute, except in improved technique, for the soil surveys carried out in the 1940-55 period as a basis for land development or for subsequent soil and plant research under irrigation in this region.

Of quite a different type and marking a sound beginning to soil studies in the arid zone was the reconnaissance of 50,000 sq miles in the north-west of South Australia (Jessup 1951). Previously little was known of this semi-desert region with a 6-8 in. rainfall, particularly of its soils and ecology, although it had long been held under grazing lease. This survey was a notable contribution to soils knowledge of arid Australian lands and incidentally the product of a great deal of arduous and lonely traversing. Jessup (see Section VII) and others have built their later pedological investigations on this north-west survey and it is worthy of mention for its originality and priority. In quite a different climatic environment the great part, over 3000 sq miles, of the South-east of South Australia was surveyed in varying detail, usefully preceding the extensive settlement of its low-fertility lands which were untouched before 1945.

In Queensland, an important survey (Hubble and Thompson 1953) covered 1175 sq miles in the Burdekin River valley, which it was proposed to irrigate from a new dam on the upper river. Queensland has a considerable potential for irrigation not yet realized, and the Burdekin project was the first move, though proving, unfortunately, more limited in its usefulness for the anticipated cropping programme than originally hoped.

In Tasmania a long series of sectional surveys finally saw the completed map of the Launceston basin aggregating almost 800 sq miles. This covered some of the most productive land in the State as a large continuous area, the agronomic problems of which have since been closely studied. The relation of these to soil types and the extrapolation of research findings through the soil map became an established practice, perhaps more closely utilized there than in any of the other States.

A notable soil survey during the war period was the 1944 work in the East Kimberley region of Western Australia by officers of the State Departments of Agriculture and of Lands and Survey. A reconnaissance embraced 750,000 ac between Wyndham, W.A., and the Northern Territory border, but most effort went into a detailed mapping of 86,000 ac of plains adjoining the Ord River. This was the first major soil survey in Australia's far north. Its great importance was in providing a sound basis not only for the present Ord River irrigation scheme but also for the forthcoming enlargement of it after construction of a major dam on the river (unpublished report, G.H. Burvill, Department of Agriculture, W.A.).

The coastal belt in Western Australia from Perth southward, covering 1500 sq miles, was surveyed, some of it in detail as potential irrigation areas, in the 1950-55 period. Similarly after 1945, 2700 sq miles of virgin scrub and low-fertility land in the higher-rainfall zone of south-west Western Australia was examined, again partly in detail, as a working basis for post-war land settlement. Western Australia had not made the same progress in development as other States in southern Australia, partly due to difficulties of scrub clearance and partly due to mineral deficiencies of the soils. The drive for settlement of servicemen and the remedying of mineral deficiencies, particularly copper and zinc requirements, made these surveys highly important and useful.

There were, of course, a great many other surveys on a lesser scale. The few examples mentioned from most States illustrate the intensity and the achievements of soil surveys from 1940 to 1955 by a relatively small band of pedologists.

The burst of post-war soil surveying and the call for it from Government and private bodies caused the setting up of survey units outside the CSIRO Division of Soils, which had carried the main responsibility for 20 years. Contributory organizations were the Departments of Agriculture in Victoria and New South Wales, the Soil Conservation Authority of Victoria, the Water Conservation and Irrigation Commission in New South Wales, the Bureau of Investigation, Queensland, the Universities of Melbourne and Sydney, and several State Forestry Commissions. Within CSIRO the Land Research and Regional Survey Section (later Division of Land Research) became a very important unit in surveying vast areas in northern Australia.

The techniques and skills improved with advances in pedological research and the liberal injection of geomorphology as a working aid. As time went on there were radical differences in approach due to the recognition of the principles governing soil occurrence in various kinds of landscape. With present progress it is very reasonable to suppose, with no disrespect at all to the earlier work, that a good number of the surveys of both dry and irrigation areas done in the 1940s would have different treatment, and show some different results, on re-examination twenty years later.

Land System Surveys

In 1946, surveys as a study of resources of northern Australia were called for by the Commonwealth Government as part of a political policy with defence overtones. Partly due to changing political viewpoints and partly as the result of the surveys, the north has remained in much the same state agriculturally as it was then. It is only in very recent times that the results of agricultural research arising from the surveys have spurred both Government and, more particularly, private enterprise to make use of selected parts of the north for improved pastures and some arable crops.

The surveys, which were carried out by a newly created body in CSIRO, - the Land Research and Regional Survey Section - were an attack on the huge undertaking to evaluate the soil and plant resources of tropical Australia making use of different systems from those discussed previously. The traversing for the first time of this near-empty region by scientists trained in agricultural, biological, and physical sciences amassed valuable data on the features of the landscape and its agricultural value. As "land" surveying in the broad sense this work stands beside the soil surveying carried through in the southern and in the more settled parts of Australia.

The surveys were of a different type from the kind of soil work mentioned earlier. They should be judged on their objective which is not quite the same as the traditional soil survey. This should not be interpreted as meaning that they were from the soil aspect any better than reconnaissance soil surveys in southern Australia; in fact in this regard they seemed less satisfactory. A series of these resources surveys (e.g. Christian and Stewart 1952; Christian *et al.* 1954; Perry *et al.* 1962; Speck *et al.* 1964) covered the greater part of Australia north of lat. 26°S., including representative desert areas.

The surveys were broad-scale reconnaissance mapping of very large unit areas of cattle-grazing country, either virgin or with development at a low level. They involved consideration of almost all aspects of the environment and took account of economic and even sociological factors. They were based on interpretation of aerial photographs, keyed by land traverses transecting, as far as accessibility allowed, the various types of country of which the geology, geomorphology, and ecology were deduced from the photographs in advance. In consequence a large volume of data was assembled for each survey, the usefulness and considerable scientific merit of which are outside the scope of this review. But there is no doubt these surveys, scientifically observing and defining many field features for the first time and mapping vast areas of virtually undeveloped land, have been of great value in authentically summing up the broad agricultural resources of northern Australia. As it happened, the specific soils aspect often contributed only a fraction to the whole.

For the purposes of these reconnaissance surveys a new mapping unit was devised. To view the whole landscape and the soil picture on a broad canvas, the geomorphological approach was adopted. Indeed, it was the first time in Australia, and possibly in the world, that a survey was orientated in this way. The units for dividing the landscape were called "land systems" and the emphasis throughout is on *land*, not soil. The land system was defined briefly as "an area or group of areas throughout which there is a recurring pattern of topography, soils, and vegetation" (Christian and Stewart 1952), which is an enlargement of the concept of soil association mentioned previously, by the introduction and emphasis of environmental factors.

The techniques of land system survey apply particularly to country at a low state of development, handicapped by, for example, climatic hazards or low-fertility soils. It is thought that it does not meet the requirements of surveys for intensifying land use, when the soil factor becomes increasingly important. From the soils point of view, low-intensity land use calls for not more than generalized descriptive terminology of soils or the use of broad units such as great soil groups. The value of the land system technique lies in its rapid definition of areas of stable, if scanty, utilization and in broadly indicating zones for more intensive study in regions at present of low agricultural development. It should always be kept in mind that geomorphology is an aid to soil survey but must never dominate the mapping or classification of soils any more than should the vegetation association. Land use may be approached dominantly via the soil or the environment. In the large reconnaissance surveys using the land system the environment dominates the soils but once detail is sought on areas for more intensive use the soil and its properties become the important, probably principal, consideration. The land system does not lend itself to this refinement and other mapping systems are more profitably used.

Engineering Pedology

An interesting development during 1941-44 was the attempt to relate soils, defined pedologically, to their engineering character. This is merely a matter of land use in a different form from the agricultural, and it seems logically practicable to apply the concept in a parallel way to engineering geology.

Under the pressure of defence requirements in 1941 and the considered necessity for urgent location of new airstrips, pedological soil surveys were made on about 20 sites in southern and eastern Australia with a view to establishing their engineering character. It became clear that differences in morphology of profiles, thought significant in agricultural terms, were not always so for engineering use. In general the distinctions were too fine in the soil types, as became evident on applying engineering laboratory tests, but a good deal of useful experience on the limitations was built up at the time.

A development from these surveys was stabilization of natural surfaces. Where suitable gravel or other material was available, a new runway might be constructed with varying pavement thickness depending on the soil subgrade at the site, which in practice was usually the B horizon of the profile. Otherwise the use of soil cement was investigated - a quite new departure for Australian engineers. Details of construction became more a matter for the pedologist and soil physicist and these workers came actively into the engineering field. The surveying and testing were carried through to New Guinea during the later war years in association with American engineers.

In the post-war years similar attention was paid to engineering pedology in relation to stability of building foundations. The soils of the Adelaide region had shown expansion and shrinkage qualities causing damage to houses and small buildings on foundations based at shallow depths. This was studied from the engineering side on the soil types which were defined first on a pedological basis as varieties within great soil groups and then correlated with degrees of cracking damage in structures built on them. The work ended in a very useful publication (Aitchison, Sprigg, and Cochrane 1954) giving a pedological classification and allied engineering values of the soils. Unfortunately, although some work was done in the Melbourne region, the line of study was not carried on more widely and only in very recent times has it been revived in Adelaide. This is a little surprising as much freer use is made in America of pedological soil types for engineering application, even those devised for agricultural purposes. In Australia up to 1955 pedological skill had not, with very few exceptions, been conceded as a useful complementary aid in engineering assessment of soils for such purposes as building design and for road location and design, although problem soils clearly occurred.

Sampling and Description of Soil Profiles

Through the wide development of soil surveys during the second stage under review two aspects came into prominence: first the efficiency of sampling for analysis, and second, descriptive terminology. It must be admitted that sampling of profile horizons in the early period of soil surveys was neither as careful nor as complete as desired later. Initially, most samples other than the surface layer were taken with a 4-inch auger, liable to give some, though probably not great, contamination of individual horizons. In addition only a few profiles were taken to characterize a particular soil type. The description relied a great deal on colour and texture. From 1940 pit sampling was standardized, a greater attempt was made to obtain better samples, and in the laboratory, analytical requirements came under increasingly critical scrutiny. Soil horizons were defined as accurately as possible from pits and discussion arose as to whether discarding of transition layers was justified, since they might well be as characteristic of the profile morphology and stage of genesis as the clearly identifiable horizons. There is now much less tendency to discard merging zones between horizons than 20 years ago.

Description became much more detailed. Conformity with American practice was sought, but not zealously. The sampling details for field use were largely based on the record sheets used by the United States Soil Survey, though varying in particular features. Environment was described in some detail, including geomorphology, location in the landscape, geology and parent material as far as known, soil origin, macrorelief and microrelief, surface drainage, erosion, land use either natural or cultivated, and quality of any crop. This gave an intelligible background for interpreting the soil profile. The profile description defined the horizons, their colour, texture, consistence and density, ancillary materials such as gravel, gypsum, carbonates, and organic matter, and the development of structural aggregates, compacted layers, and hardpans. The full details of description of structure and consistency for profiles was set out later explicitly by Butler (1955) and has not been greatly modified since. These conform well with the American system as described in the 1951 U.S.D.A. Soil Survey Manual. While the Munsell colour symbols were used in practice towards the end of the period the descriptive colour names remained the same as those devised earlier for the Australian surveys.

IV. TIMES OF CHANGE

It was mentioned in Section I that the opening of the third stage in the history of soil survey might conveniently be placed at 1955. There are several good reasons for this and one of the most significant is a change in viewpoint on what a soil survey should aim at and with what form of classification.

The Russian concept, dating back to the last century, was that the soil profile is the integrated product of soil-forming factors - climate, parent material, biotic agencies, and relief, combined variously within a time scale. This has been generally accepted in principle. Its corollary is that the nature, and therefore classification, of a soil is expressed in its morphology from which may be deduced the characteristics of significance for any land use whether it be agricultural, silvicultural, or engineering, or as an aid in interpretation of geomorphology and surface geology. It was the business of soil survey to classify soils with relevance to land use.

There were voices being raised in the 1950s contesting some of the principles followed in Australian soil survey in regard to classification and the type of survey being made. There are two main schools of classifiers, one which claims they are pure morphologists and one which liberally uses genetic deductions. For example, the creation of great soil groups is essentially based on pedogenetic hypotheses, few of which can be proved by experimentation in normal terms. Those who use great soil group classification must make or accept genetic assumptions. To most field pedologists it seemed inconceivable that pedogenesis could be by-passed. The very variability of soils made it essential to understand, as well as evidence permitted, the factors governing the appearance of a particular soil in a particular landscape, that is, the operative soil-forming factors and the chemical and physical changes arising from their *in situ* effects. To a considerable extent this was considered in the "geographic" method of soil survey when environmental factors were consciously or otherwise drawn into the formulation of soil groups or soil types and of course genetically in the great soil groups. Now soil classification would be straightforward, or no more difficult than classification in biological science, if it were not for the lack of inheritable characters and for the frequent variability of soils over short distances. A soil survey is done for the better use of land and not as an exercise in soil classification. All features that may affect plant response need to be considered in balance. A soil type has no practical identity without reference to its use and any soil unit must have a mappable extent. These were some of the features governing soil classification and survey in Australia 10 to 15 years ago.

Then a new stage in the history of Australian soil survey was entered about 1955. There were four reasons for this change.

First, after 1950 the volume of requests for soil surveys from Government and other agencies declined rather sharply so that the demand for rapid assessment of areas for successful settlement dwindled.

Second, a wave of criticism of soil classification gathered force so that doubts arose, and increased, on the efficacy of the systems previously used.

Third, there was a rise in interest in research in field pedology reducing availability of skilled surveyors.

Fourth, there was a strong swing from soil survey as such to land survey.

Some of these reasons will be brought out more explicitly during subsequent discussion (Section V) and there is no doubt they did influence the modern trend away from the previously traditional survey practice.

In the post-war period the demand for settlement of servicemen was largely met by the mid 1950s when Commonwealth interest in land development, even in its Territories, virtually ceased. The State Governments followed a variable policy of soil surveying with fluctuating enthusiasm and staff numbers. This was not such a happy period for soil survey, which at no time was strongly staffed, considering the necessity to examine and map as adequately as possible the soil resources of Australia as a basis for future development. In particular, in view of the vast extent of low-fertility land coming into prominence, the problems of production needed to be attacked with, initially, a proper assessment of the soil factor. That so much information and knowledge about the arable soils of Australia had been gathered by so few surveyors is a tribute to their skill and activity. CSIRO was the dominant body and worked in all parts of the Commonwealth and Territories; its policy therefore was the principal key to progress in soil mapping.

It was fortunate then that the mass of soil survey was accomplished in the first 30 years, since a major decline, except in land survey, has occurred in the last 10 years. At this stage, before discussing the work since 1955, it is desirable to examine other reasons for the change and the criticisms which arose on soil classification.

The general assumptions on soil classification and survey for the first 25 years of Australian work had scarcely changed.* For the initiated, the techniques were accepted as giving useful results, and to the layman, soil surveys seemed to answer his requirements so well that a good deal of blind faith in them developed. Without doubt in many significant cases the field surveys were successful on the score of amassing observations on "soil types" from which workable interpretations could be made to correlate soils and problems in land use. An excellent example of this was the specifications set out by Northcote (1948) for crop-soil type relations in the irrigation settlements of the Murray valley, which served as a basis for planning horticultural planting on new areas. Northcote built on the experience of all those who had been surveying along the Murray River for the previous 20 years. From the mass of observations and experience relating soil type to crop response, he was able to lay down soil criteria for the successful growth of citrus, stone fruits, prunes, vines, and figs. These criteria essentially turned on the depth and texture of soil horizons overlying the calcareous layers always present in mallee highland soils. Now these conditions

*As evidence *vide* Stephens's (1952) compilation for F.A.O. which was cast in the traditional approach and coloured by Australian experience and opinion.

have been used extensively in evaluating similar soils of new areas in the Murray valley for planting and planning farm layout and for drainage requirements. In recent years there has been some review of the soil specifications, but in few other cases has such a large amount of background data been accumulated on which to base assessments. The surveys in the Western Australian wheat belt mentioned in Section II are the only comparable cases where surveys have set up workable yardsticks to assess the soundness of soil types for cropping. The point some critics have made is that perhaps it may not be necessary to go through extensive surveys and mapping to evolve the criteria. Is it necessary to give names to soils and map their boundaries when the same criteria are applied? For example in a field examination of at least one area before planting in the mallee highland along the Murray River in South Australia, soil examination was reduced to the simplest terms of noting the depth to a stony lime pan at frequent intervals. This may be arguing in a circle as the significance of the limestone and its depth would not have been appreciated before soil surveys demonstrated it, by relating soil profiles to plant responses.

But to turn to the attack on the basis of soil classification. Leeper (1952, 1954, 1955), questioning the soundness of the usual categories, in particular the great soil groups, provided the platform for subsequent discussion.*

In his thesis Leeper used four points which may be simply and briefly stated. First, there is no such thing as a natural soil body. This idea was disputed strongly, and many Australian soil surveyors still hold the contrary view, though perhaps with not quite the same intensity of faith in this item of pedological dogma, shared by the majority of pedologists in America and Europe. In other countries it is rather implicitly accepted that a soil "type" *is* a natural body. The argument against it is briefly that soil has no inherited qualities and is the product of the environment and in consequence infinitely variable; it can only be delineated by drawing arbitrary boundaries. Secondly, it is essential for reasons of scientific accuracy to describe soils as they are, not hypothetically as may be imagined as the product of unproven genetical processes. While it may be convenient to assume that processes such as, for example, are understood by the term podzolization, do occur, this should not be the basis of classification. Deduced genesis should give way to factual observation. Thirdly, the basic considerations in soil classification are soil properties distinguished as present or absent or by contrast, and all determinable by morphological examination or simple field test. This follows directly from the second point. Soils are different because of the presence of some attributes. In comment the difficulty to be resolved is what attributes in descending order of priority are to be used in working out a new key for classification, and this could be a matter of personal choice resulting in confusion between classifiers. Fourthly, any new system to be effective must start

*An earlier paper (Leeper 1943) was the first published criticism, but it did not have any appreciable impact on orthodox survey at the time.

de novo, proceeding by logical steps and not by attempting to patch the old system.

It came to be realized more widely that the great soil group classification had its vulnerable aspects. The groups have been set up by assembling properties noted in soils in a region, finding they do not conform to established groups, and therefore creating a new unit. Any pedologist can define a new group and there are no set rules governing validity. It is very difficult, if not impossible, to correlate soil groups between countries by description alone. The present great soil group classification is not like a periodic table with places for soils not yet found. Experience has shown that unless the classificatory pigeonholes are made flexible there seems scarcely any limit to the number required in viewing world soils.* In any case if they are made broader the groups would become increasingly less significant and useful. The great soil group category remains a collection of entities, defined as circumstances presented the soils, each with a set of characteristics considered by its originator sufficient to separate it from previously defined units. According as the occurrences of a new soil group as first presented permit, a modal profile is set up to which future observations may give population boundaries depending on other pedologists' concept of it. Definite rules for soil taxonomy have not yet been set down, not even a proper system of group registration.

Leeper was in conflict with this state of affairs and advocated the complete discarding of the great soil groups and substituting, on the premise of the third point in his thesis, a new system based on the presence or absence of selected soil attributes. This proposal was discussed at length by a Committee on Soil Classification, drawn from the body of active soil surveyors and including Leeper, in 1953.† The Committee reported as a majority with some favour on the possibilities of Leeper's idea on classification and agreed it was sufficiently important to put into practice as a trial, although a very large number of difficulties had arisen in their exploratory attempts to do so. Indeed, many flaws were pointed out by working pedologists and it was in part viewed as an armchair approach in devising a system. At that stage (1955) the implementation of the scheme failed to make progress. As with many new things of a radical nature, liable to upset long-accepted and cherished ideas, there was not a concerted move to give it a trial. Some who did were disheartened to find separate profiles from one soil type yielded different results, although the assumption had been made that the occurrences of the soil type were actually identical. Northcote was the most persistent tester and improver of the system and it was he who finally devised a key to soil classification on the bifurcating, presence or absence principle, which has become the greatest advance in this field in recent times.

*In Australia the current total is about 50 and in the world well over 100 groups.

†See several unpublished reports of the Committee in 1954 and also Leeper (1954).

Leeper's argument, though it did not shake the thinking of international pedologists, did raise in Australia an important wave of critical discussion of previously accepted dogma on soil classification. It says a good deal for the openness of mind of Australian pedologists that such a revolutionary concept should have been given any blessing. It was not, of course, without considerable opposition and the old great soil group principle had powerful champions. What the argument did achieve ultimately was a good deal of soul searching by pedologists on the principles of classification and a feeling that a new approach at least at levels below the great soil group was desirable. As it turned out, Northcote (1960) produced a promising answer some years later (see Section V).

Although the Northcote system of classification supplied a need, the great soil group was not given up even by those honestly seeking a new unit. It still continues in practice but probably the great soil group usage became more restricted; subgroups of a more definitive nature were used as mapping entities and more specific correlations made of the soil groups, lithology, and land form.

A second major debate also began about the mid 1950s with a strong criticism of the conventional soil type as a mapping unit by B.E. Butler. His principal paper (Butler 1957) set out his conclusions that the approach to soil study in the field is along three lines which he called the edaphic, the geographic, and the pedologic concepts. The edaphic is concerned with plant response to soil character, the pedologic with the origin of, and the principles of occurrence of, soils, the geographic, with soils in a landscape. The conventional soil survey comes in the geographic group where, for classification, the soil is assessed as the *principal* factor in an assembly of environmental features including topography, lithology, and vegetation. Butler argued that the great bulk of soil surveying had been on this geographic basis, that the entities of soil types had become empirical, that they did not serve to illuminate pedological studies sufficiently, and were of undefined use on the edaphic side, even to the extent of being misleading. On the other hand he agreed the conventional geographic soil survey had provided a basis for edaphic study in dividing the soils of a landscape into units of a certain character. These units by combining features of botanical, geological, geomorphological, and microclimatic significance enabled some assessment of potential value of the soils from which edaphic research might reasonably start. Butler's use of "edaphic" is synonymous with crop productivity. Butler finally proposed that the current soil survey involving soil types was of minor value for pedological research and if anything a classification might even better arise by the reverse route.* In any case he maintained that, as it did not serve for edaphic studies, which was the most important function, some other approach was necessary, since there is no object in soil

*For an example of this see Churchward (1960).

survey without its application to productivity questions.*

Butler aimed his main criticism at the inadequacy of the soil type in assessing edaphic values and hence the conventional methods of classification at any level from soil type to great soil group needed replacement. He wrote (private communication, 1961), "We simply do not know enough about soils to classify them effectively. The things which are important are soil history, soil processes, soil plant relations, soil properties. In classification (for mapping) we put many soils together into a group with the anticipation that for certain uses, as yet unspecified, all of these soils may be treated as one... We cannot expect that a classification scheme devised in the absence of soil-plant data, constructed in default on the basis of certain pedologic notions, is likely to achieve the same end." He argued strongly against the existence of natural soil groups and the assumption that such could have uniformity in history, processes, and soil fertility. Such correlation cannot on scientific grounds be assumed without proof and practically nothing has been done to secure such proof.

Butler then proposed a programme of work in soil-plant interrelations to follow a general "geographic" mapping of a region in land types and a study of the pedological principles of the region. Edaphic differentials should then be established between the soils and finally correlations sought between plant growth responses and soil morphology (aided if necessary by some laboratory tests) so that meaningful units may be mapped out in the landscape.

Butler's argument met a good deal of criticism although at the same time there was agreement on a number of points. It was thought the old soil type had defects as a mapping unit, especially in its implied plant relationships. Wider groups were considered better as a basis for both more intensive agronomic investigation, as in Tasmania, and more extensive forms of study, as in Queensland. There was scepticism as to whether mapping units based on productivity relationships would be any better than the pedologic soil type. Hubble (private communication, 1961) summed this up, "It is difficult to see the possibility of mapping the edaphic differences other than through their relationship to the features at present used in detailed soil mapping. Because in general the same kinds of data must be used in mapping and there will be the same limitations to the number of observations or samples, we can hardly expect a higher order or reliability than in detailed survey. The task may be simpler to the degree that fewer boundaries may be necessary but there is the possibility that separate mapping may be needed for different groups or remapping as further research and experience bring to light new edaphic controls."

Certainly it was agreed by all wholeheartedly that investigation of edaphic differentials between soil units, however devised or mapped,

*Over the years between 1957 and 1962 a large amount of discussion took place on Butler's thesis within the CSIRO Division of Soils. There are no published records of the considerable correspondence and discussion at meetings of senior pedologists but the general attitude is given in the comments which follow.

should proceed, and there were different approaches to this (see Section VI). Indeed, once more the undesirability of thinking all conditions in Australia might be met by a common plan of soil study was emphasized. Mapping techniques and classification units are in our experience geared to the environment and the objectives of the survey. It is probable that because in the last decade so much effort has gone into less-developed parts of Australia, the great soil group (and subgroup) has held its place as a field unit, despite criticism of its logicality. Conversely if every pedologist had been faced with the environment of south-eastern Australia in which Butler developed his argument there might have been less disagreement. The conventional soil type may be, for edaphic purposes, too fine a distinction to work from in some cases and too coarse in others. The basis for edaphic study may be a broader group initially, whether it be the Northcote principal profile form (see below), subgroups of great soil groups, soild on specific geomorphic surfaces, soils under descriptive titles, or one arising from pedological study of the area.

It has been noted that after about 1950 the requests for surveys from Governments and institutions stopped so that field pedologists were free to undertake work of their own choosing. This itself led to a different attitude to surveys and a strong development of pedological research (see Section VII). But it is clear that the high tide of surveying rather quickly began to ebb after 1955. The close detailed surveys dwindled almost to a stop in the next 5 years* and the old association surveys declined, partly because there was no official demand and partly because the pedologists, through lack of personal satisfaction in the work or feeling it was of doubtful value, tended to move into pedological research with lesser mapping objective. Those who did continue had different motivating influences, as described later (Section V).

In this atmosphere Northcote (1960) put out his scheme of classification based on a purely morphological key, discarding great soil groups and lower categories. The key was prepared for the programme of mapping the soils of Australia in 10 geographic regions since the existing soils resource maps, using great soil groups classification, were considered unsatisfactory (for further detail see Section V). The criticism of the validity of soil classification with the old established units had begun to achieve significance although their substitutes were not yet fully defined or not completely accepted. Although Northcote's system is quoted widely, and is used in a few cases by others for broad soil survey purposes, it has not been adopted generally by the present generation of surveyors. This is not from prejudice but quite possibly due to the difficulty of changing to a new descriptive technique and a feeling that modifications of the older systems still had a useful purpose.

The fourth factor in causing change was the emphasis being increasingly placed on land as the environment for plant growth. As indicated above, Butler recognized that the old soil type was a

*Except in Victoria; see Soil Survey Publications and Technical Bulletin Series of the Department of Agriculture, 1962-66.

geographic unit, not purely soil, though the soil was the ultimate thing mapped. Now the move was coming to map "land" in which the soil could be of small to dominant consideration. Land mapping has supplanted the old soil survey in many areas, more usefully perhaps in new lands employing simple farming systems (see Section V for discussion).

V. THE CHANGING PATTERN, 1955-65

The slackening of the pace of the soil survey programme, for reasons discussed in the last chapter, only slowly affected the volume of work. Initially extension of new areas soil surveyed occurred through the impetus from earlier field work. It was just that as units were completed, the move to new ones was slower or the tendency was towards broad-scale studies. Although a number of workers turned to field pedology others, with less aptitude for this or with a continuing interest in survey, carried on with it, particularly in the two States with a powerful developmental programme - Western Australia and Queensland. Intensive work still proceeded, principally by surveyors in the Victorian Department of Agriculture, who have been responsible for mapping in considerable detail about 1 million acres of the Riverine Plain of the Murray River and its southern tributaries. The New South Wales Irrigation Commission has quietly gone forward with detailed mapping on new areas proposed for irrigation. There has been extensive work by the Victorian and South Australian State authorities described in detail later as land survey.

The progress of surveying at all levels is summarized in Table 3 for the 1956-66 period.

TABLE 3

Area covered by Soil Surveys, 1956-66

State	Detailed Surveys		Broad-scale Surveys	Reconnaissance Surveys
	Irrigation (ac)	Rainfall (ac)	(sq miles)	(sq miles)
South Australia		50,000	4,000	11,650
Victoria	1,041,000	4,000	4,500	-
New South Wales	-	175,000	10,300	27,000
Queensland	-	-	75,300	150,000*
Tasmania	-	-	2,475	-
Western Australia		252,000	1,212	
North Australia	-	-	25,000	144,000*
Total	1,041,000	481,000	122,787	437,650

*These areas were covered in resources surveys by the CSIRO Division of Land Research which included field data on the soils but were not basically soil surveys. In addition areas totalling 30,000 sq miles in New Guinea have been covered similarly by the Division of Land Research.

Returning to the character of the reduced programme of surveys after 1955, there is more specific objectivity in the field work orienting it to significant soil features affecting productivity, or turning towards pedological research, or leading to broad-scale land use and soil resource mapping. This may best be illustrated by describing briefly a number of typical surveys in recent years to show their aims and how they differed from earlier ones. The selection conveniently emphasizes the individuality of the surveys in the present period, but many others could also be chosen for their distinctiveness if space permitted.

Analyses of Typical Soil Surveys

The *Yudnapinna survey, South Australia,* 1300 sq miles (Jackson 1958), began as a normal soil mapping programme in the traditional form of a series of detailed "spot surveys" linked later into an overall pattern of soil associations for the whole area. This perhaps was necessary to understand the problems of land use in this semi-arid environment, a usage which turned much on management and non-soil factors and was subject to erosional and hydrological controls. The latter point came out during the survey when the absolute dependence of the grazing animal on water conserved in surface dams was clearly evident. By itself the survey achieved little at the mapping stage but the subsequent investigation of internal and external hydrology of the soils was of great value. By infiltration trials the absorbing capacity of key soil types and the depth of penetration of rain into them were demonstrated over a wide range. This was related to water storage in the profile, to field capacity of the upper soil, and to the potential run-off from catchment areas to dams. In such country there are water-absorbing, water-shedding, and water-accumulating parts of the landscape and the definition of these is the key to water conservation in soil and in dams. The soil "types", therefore, are significant for their water-absorbing and water-retaining capacity rather than for their pedological character. The Yudnapinna survey was one of the first to be allied with field experimentation and the explanation of soil problems whose solution was essential for successful management.

The area also could have been mapped in different units by consideration of the topography and the internal hydrology of the soils rather than in terms of pedologic classification. However, the point to be emphasized is the aim, the experimentation, and the conclusion in the survey, as an example of a new form.

The *Merredin survey, Western Australia,* 875 sq miles (Bettenay and Hingston 1961), was essentially a study of soils and ground surfaces as a background to research in field pedology. It certainly set out the soil pattern in soil associations and tied it in with salinity and productivity. There were no new data produced on land use aspects. Its object more particularly was the definition of geomorphic surfaces in the eastern part of the wheat belt, partly as an extension of the work on lateritic formations in the York district (Mulcahy and Hingston 1961), and partly as a step in the pedological understanding of the salinity problem in a typical valley system in this region. It is one answer to the question, should pedological research follow and build on a soil survey as a prerequisite? It did not, and scarcely could be expected to, affect the agricultural improvement of the district but as a preliminary part of a wider piece of pedological research it showed a new objective.

The *Kempsey survey, New South Wales,* 450 sq miles (Walker 1963), arose from the discussion of two questions of active interest to the dairying industry in the lower Macleay River valley. The first was whether intensification of use of land in the coastal delta area was practicable and the second whether pastures for dairy production should be extended over parts of the valley slopes. The survey revealed the array of soils as associations in both situations. The analysis of climatic data showed the soil-water regimes were likely to exist seasonally, which indicated that the second proposal as far as dairy practice was concerned was not feasible. The interpretation of laboratory data coupled with field observation pointed to the problems, previously not appreciated, facing the development of the river delta area. The investigation did therefore achieve its objective, but it went a long way past a soil survey as such. Let it be emphasized again that the more recent surveys have been aimed at studying specific problems and their solution, or at least clarification has been part of the investigation. The soil map may in consequence be secondary. The Kempsey work is quite comparable to the Yudnapinna investigation mentioned above and allows a conclusion, not an opinion only, to be stated. For many years soil surveyors had been interested in but unable to conduct investigations, after the actual soil mapping, in various aspects of productivity. This was due partly to the policy being followed of seeking to prepare a base on which agronomic and other work might be built by others, and partly to pressure to produce soil maps and field opinions on land use as quickly as possible; there was also a lack of facilities or skilled collaborators to study, for example, infertility problems of defined soil types. With the reduction in demand for surveys officially came the opportunity for attacking specific objectives through surveys whether in answer to a problem as at Kempsey, as a basis for pedological research as at Merredin, or as a means of studying questions of fertility and productivity in a region as in the Dorrigo district (see below).

As a different example the *Liveringa survey, Western Australia,* 400 sq miles (Churchward and Bettenay 1962), is of interest, firstly in attempting to answer a land use question by mapping in units other than conventional soils associations or types, and secondly in applying a technique proved in the Riverine Plain of south-eastern Australia to alluvial soils in the far north of Western Australia. The proposal was to use soils on the recent and older terraces of the Fitzroy River, Western Australia, for growing rice under irrigation, which in principle is comparable with the position in the Murrumbidgee valley of New South Wales. It had been shown in the latter that ground surfaces of different age and origin were found superposed to give multi-storey profiles within shallow depths. This is a quite logical occurrence with deposition of riverine and/or aeolian materials, but from the point of view of the soil surveyor, classifying soils into types on profile morphology alone, it poses an almost insoluble problem in accurate mapping. Mapping at Liveringa was therefore done by ground surfaces, separated on the basis of their different nature and age; some of them reached the surface and some were always buried. The suitability for irrigation and crop type of any part of the area was decided according to the character of the underlying layers which usually formed part of older buried profiles. The soil series then defined and the soil associations mapped were complicated by this feature, especially as the textural sequence with depth usually included an underlying, older layer of very fine texture. It is clear a survey without definition of ground surfaces would have been inadequate but, having defined them, the less detail attempted in putting specific soil series boundaries on the map would be an advantage, indeed a necessity. A better step in a case like the Liveringa area would be to proceed from the ground surfaces map to a land use map based on field judgment, especially for a monocrop system such as rice.

The Liveringa work was valuable in the application of pedological principles to mapping in deciding on land use, which fortunately could be done because the physical state alone, as expressed in field character, governed the possibility of development. It was obviously easier and more correct to attack the problem in the virgin Liveringa area for an understanding of water infiltration and seepage qualities of multi-storey profiles after the method had been fully studies and applied to aeolian and riverine soils at Woorinen, Victoria (Churchward 1960).

The *Dorrigo survey, New South Wales,* 400 sq miles (McArthur 1964), was associated with soil fertility investigations and designed to answer problems in land utilization in a high-rainfall area of declining agricultural fortune. The soils were mapped as associations, based on parent material and pedological grouping and with due regard to the variation in rainfall in the area. The survey was broad without attention to variations or soil subgroups and it proved adequate as a background for conducting fertility investigations. Vegetation was studied as a further key to soil distribution to which tree communities could be allied. But if an answer is sought as to why the district is in the doldrums, the broad soil pattern with a characterization of soil deficiencies for the soil groups, derived from field and glass-house tests and combined with analysis of climatic data, affords a good working basis for further study. None of the agronomic problems can be finally solved until the test of field experiment is made. The survey aimed at providing this information for agronomic work and, what is possibly more valuable, for the field examination of problems on the farm itself. It is in line with the more modern trend to begin with a general survey in relatively broad soil groups, and to use this as the groundwork for study of specific questions; then, *and only if necessary,* at a later stage proceed to map in appropriate units at any degree of detail required, preferably using lesser technical skills for the survey. This agrees with the change in viewpoint on survey discussed in Sections IV and VI.

The survey of the *brigalow lands in Queensland and New South Wales* (Isbell 1962) was of quite a different type. A very large area of country with brigalow (*Acacia harpophylla*) as a dominant or constant component of the vegetation extends from south of Mackay through central Queensland into northern New South Wales. Of this zone 20,000 sq miles were traversed and mapped, but not in conventional units of soil associations or families. The units were literally groups of soils based on features set up as distinctive and essentially related to mode of formation and parent material. This classification was evolved to fit with the scale of mapping, which precluded any detail being used, and to be adequate for the type of extensive land use in view. All surveys, of course, are, or should be, geared to the type and intensity of land use.

The soils were divided into five groups of which two were equally dominant in different parts of the brigalow belt and these together covered 86% of the area. The basis of recognition was roughly the degree of gilgai formation and whether the soils were transported or sedentary, the latter being reflected in profile characteristics due to parent material and type of macrorelief. Many features of both were generally common but from the land use aspect, particularly arable agriculture, they were considered sufficiently distinctive. Of the remaining three groups of less material significance, one was a miscellany of clay soils, one included all alluvial soils subject to periodical inundation, and one was a coarse-textured group in a low-rainfall region.

It was convenient to use the brigalow tree as a discriminating factor although there are many areas of similar soils on which brigalow does not grow and conversely many other trees and shrubs grow with the brigalow on the areas mapped. The survey aimed at giving a broad picture of the lands currently carrying this indicator tree and a lead to development of such areas. It should not be regarded as the end point of soil mapping in the region; the next stage should come when, beginning with the broad groups, more is learnt of their agricultural variability and properties. What is important to this review is that while this was a kind of soil survey it was designedly much less precise than the conventional type and was essentially a reconnaissance of *land*. In some ways it was therefore a resource study, less important in its definition of small unit areas of the different groups, but rather a summation of the whole brigalow soil resource.

The brigalow lands survey was a magnificent effort to see the soils of a huge area at such a low level of improvement in good perspective. This is the kind of approach which would have paid dividends at an earlier stage of soil survey in Australia. Perhaps the earlier study of the smaller but still large area (6000 sq miles) of the South-east of South Australia by Crocker (1941) is the main comparable case. Another, by Burvill in 1944, is the reconnaissance of 1200 sq miles in the Ord River region of Western Australia. The mapping in combinations of great soil groups of the Macquarie region, New South Wales, 24,000 sq miles (Downes and Sleeman 1955), is another example, perhaps qualified as being in a region of long-established agricultural development and greater accessibility.

Objectives of Soil Surveys

All the surveys outlined above, and others carried out in the last 10 years, are removed in varying degrees from the traditional survey discussed in previous chapters. They are a varied form of investigation seeking explanations of known problems by using new approaches and even producing new kinds of maps. They do not only classify soils into types and map them as defined areas. The attack is much more through a specific objective concerning land use and where possible has moved on to experimental proof of field deductions. They were also not primarily concerned with *direct* applied use at the farm level which is often implicit in traditional soil survey. The United States soil survey, and a great deal of the Australian, sought to produce a soil map as the great final object which could be directly used by others, built on by agronomists for experiments, used as factual by farmers and advisers. It was coming to be realized that the farmers and advisers possibly wanted something different, that agronomists as a body were, inadvisedly, not concerning themselves closely with profile morphology, that pedological soil types needed adapting to land use, that a soil map was better cast in some form of broad unit, that it was more often the beginning than the end, and might be redrawn later or not drawn at all.

As indicated above, the more recent surveys arose for different reasons, in many cases one of the last considerations being a soil map for detailed use. They ranged from pedological research to applied study of watersheds, to demonstration of reclamation and use problems, to fertility studies, or to broad soil resources. One important question which must be answered is whether the amount of field mapping and soil definition done was always necessary to arrive at the point of conducting experimental work or reaching conclusions. This also touches the point whether a soil survey as such should precede field pedological research. There is no doubt the surveys carried out on the brigalow region (Isbell 1962), the Dorrigo area (McArthur 1964), and less certainly those at Kempsey (Walker 1963), Yudnapinna (Jackson 1958), and Liveringa (Churchward and Bettenay 1962) necessitated the classification and mapping of the soils in the form presented. It should be noted that all the maps were reduced for publication to a scale of 2 miles to 1 inch which is evidence of the lack of detail and the intended accuracy of boundaries involved. There appeared a tacit objection to seeking and showing detail of soils in complex patterns with intricate boundaries. The smoothed boundary and large-scale reproduction are typical of most soil maps generally in recent years. For practical purposes outside irrigated horticultural areas, detailed classification and mapping was very largely dropped. It was thought better to get closer to principles of soil occurrence for example by defining ground surfaces (Churchward and Bettenay 1962), or to deal with soil problems, or to obtain the general picture of distribution as in the brigalow area of Queensland (Isbell 1962).

To return to the question posed above - are field mapping and soil classification in some degree of detail necessary to arrive at the point of conducting experimental work or reaching conclusions on land use? Alternatively, would a preliminary general examination, perhaps some detailed transects, without defining soil series, show the focal points for concentration of the investigation of a problem? If so, having then set this situation out and by experimentation or observation reached a solution or a conclusion, a much simpler map or one with detail in limited areas may be made, or even no map may be necessary. For example in the Kempsey survey (Walker 1963), the discrimination of catenary sequences on the hill slopes of the Macleay River basin is, in the final analysis, of small value beside the data on the acid estuarine clays and the ground-water problem of these and the coastal sand-sheets. The demonstration of irreversible acidity of the swamp clays, the potential danger of overdrainage and salinity on the lower levee bank soils, the essential control of ground-water levels in the coastal sands with exclusion of a marine influence - these form the valuable core of the investigation. The application of this information may not need an overall soil map. This argument is advanced in the case of what is considered to be one of the best field studies made in Australian survey; it is perhaps even more pertinent with many other surveys.

There were other conventional surveys always proceeding. A total of 900 sq miles of the Darling Downs and adjacent country in Queensland was mapped by "spot" surveys and as associations (Thompson and Beckmann 1959; Beckmann and Thompson 1960). The greater part of the Barossa district, South Australia, amounting to 120,000 acres was surveyed in great detail (Northcote, Russell, and Wells 1954; Northcote 1959; Northcote and de Mooy 1957; Wells 1959). Detailed maps were constantly being made of soils on select areas such as field experiment stations and there will presumably always be a need for the latter. It is an understatement to say that there is doubt among Australian pedologists generally of the advisability of applying the same method to larger areas.

Intensive Surveys for Irrigation and Other Land Uses

In the past, irrigation areas for horticultural purposes have been examined in great detail, possibly as closely as one profile per acre. Minor variations have been used as sufficient basis for creation of new soil types. For pastoral use examinations may have averaged one profile per 10 ac with a somewhat more flexible definition of the types. For rice irrigation the sole criterion was the degree of permeability of a clay soil profile.

The present tendency is to seek a limited number of parameters. The exception is in Victoria where mapping has proceeded on conventional lines but with a subsequent aggregation of the soil types into a few groups, each suited to various horticultural crops. Surveyors in the Victorian Department of Agriculture have covered in this way, with considerable detail, 1 million acres constituting the greater part of the irrigated riverine plain and associated mallee areas of north central Victoria (Skene and Sergeant 1966). It is unlikely this system will be followed elsewhere in Australia now. Indeed, some are boldly saying the overriding feature is the drainage character of the soil to a minimum of 4 ft, preferably 6 ft, to ensure a clearance of excess water through a tile drainage installation. This probably applies if optimum crop results are not required, but in view of the cost of irrigation development, this is scarcely a sound enough base except as a starting point in reconnaissance.

Irrigation development seems to be moving to the north and, for these conditions and the likely crops, a new view should be taken. In Queensland the soil surveys of proposed irrigation areas are based on land form separations on which are superposed a mapping of Northcote's principal profile forms. This is a progressive move which would be all the better if the classification were extended further. It is essential for irrigation development that the fullest useful information on the physical nature of soil variants should be known.

The Northcote Soil Mapping System

It was mentioned in Section IV that the Northcote system of soil classification brought a new look to soil mapping, and it has been used by soil surveyors quite widely, though more as a means of characterizing their soil "types" mapped in the field on other grounds. When Northcote undertook the preparation of an Atlas of Australian Soils in 1959, he abandoned the great soil group and other classifications and set up a new basis which relied on the observable physical character of the profile and the occurrence of the soils in landscapes. He called his basic concept the "profile form", regarding it purely as a physical system, and physical characteristics which carry along other features and properties, be they chemical or biological, are used as the critical ones to distinguish between groups at each step of the key (Northcote 1960). Using this direct observational approach any skilled surveyor can readily recognize the profile form. The key appears to provide pigeonholes with a satisfactory fit for the very great body of soils found in the field and is more adaptable to the misfits. It overcomes the difficulty of classification when mapping groups are based on a modal profile with a surrounding population without fixed limits. Especially is this so as it avoids the necessity for subjective opinion on genesis. Northcote called it a "Factual key".

Northcote followed the principle put forward by Leeper (1954) in using a bifurcating system for classification based on presence or absence of selected soil properties. In its present form the classification is designed for soil mapping on a broad scale. His maps (scale 1:2,000,000) have no direct application to problems of land use but they may be refined with more detail and be used with parallel agronomic investigations. The principle of the system is sound, the only serious question being the priority given to the properties selected as distinguishing characteristics when working out a progressively eliminating order. This is still open to criticism, especially in the lower parts of the key.

Northcote set up four major Divisions as *Primary Profile Forms*:

(1) Soils with dominant organic characteristics (O)
(2) Mineral soils with uniform textural profile (U)
(3) Mineral soils with gradational textural profile (G)
(4) Mineral soils with textural differentiation in the profile (D)

From those divisions he proceeded to subdivisions of each based on such features as profile coarseness, fineness, calcareousness, and colour of B horizon. From the subdivisions the key passes to the *Principal Profile Forms* using, for separation, various features of pedologic organization such as pedality, coherence, hardpan, types of A_2 horizon, together with colours and pH trends in the profile. The principal profile form is the ultimate unit so far devised in the key and has been used as the descriptive code in preparing the 10 sheets of the Atlas of Australian Soils (Northcote 1960-68).

This type of mapping is readily adaptable by any experienced surveyor to reconnaissance or broad-scale work to yield information on the physical character of soils and their geographic distribution in a region. It has a practical aspect in dealing with physical morphology in inferring soil-moisture relationships and plant adaptability. However, it is recognized that the principal profile form is too broad a unit for more intensive soil surveying, and closer traversing only improves knowledge of the interrelationship of soils in the groups as mapped. These groups are associations of principal profile forms, as dominant and minor, combined in a topographic landscape. The key should be extended one or more steps for more detailed work if this is required.

The Atlas having been completed, a review and extension of the classification system is highly desirable. It can be said that the finer the separations, the more difficult it is to establish priority of selected characteristics. It may be as well to stop short of seeking equivalence to the soil series. Whatever may be done later, it is considered that Northcote's (1960) "Factual Key for Recognition of Australian Soils" is the best step forward in soil classification since the international systems were introduced to Australia over 30 years before. It is established as a means of mapping soil resources; its future should be linked at an appropriate level with the requirements of soil fertility investigation.

The key has been severely criticized by some pedologists, not so much in principle as in detail. It is claimed the selection of separating characteristics has not taken account of interdependence of properties, so that those not used can only be fitted to the key by experiment. But it is not clear how covariance can be established in any case except by experiment and observation. It is also said the order of priority changes at different levels proceeding down the key. The question will always arise, as in past systems, wherever arbitrary divisions have to be made, for example on the minimum significant thickness of some layer used as a distinguishing feature. One sound criterion of any key is not its rigidity but that it works and that it has enough flexibility to meet changes made necessary through emphasis in a region on features not given due weight in the original key.

Land Surveys

All the work so far dealt with in this Section has referred to the survey of *soils*. There is the alternative approach of surveying *land*. Those concerned with this adopted a broader outlook. One criticism of the soil survey was that while it showed an existing state of land use in relation to soil type, it neither looked far enough ahead nor did experimental work to improve the situation. In most surveys little was added to knowledge of land use in a practical sense that was not already available, for example, to an agricultural adviser. Some of the cases mentioned above are exceptions but it is true that the follow-up work generally was someone else's business. The bodies embarking on land surveys were better equipped to combine survey with experiment, although a great deal of the outcome published was still only informed opinion.

There have been five principal approaches in land surveying - the land system survey as outlined in Section IV (Christian and Stewart 1952), the "ecological" method (Gibbons and Downes 1964), the agricultural use mapping (French, Mathieson, and Clark 1968), and the land classification used by State Departments of Lands particularly, at present, in Western Australia. In the engineering field a fifth approach is developed from the land system using "terrain" units.

The land system surveys have been used in making a resource inventory, to break up large areas into units with presumed similar characteristics so that, if desired, an attack in more detail may be made on portions considered to have potential value for a specific use. An example of this is the soil survey of the Tipperary land systems (Speck, Wright, and van de Graaf 1965), originally defined in the survey of the Katherine-Darwin region in 1946 (Christian and Stewart 1952). The same principle was used in both but in the recent work with strong emphasis on geomorphology, as it were refining the map detail into micro-land systems. It produced no less than 20 such land systems as a break-down of the original single Tipperary land system together with a more detailed description of the soils in eight groups comprising 21 soil families. It is an interesting exercise in intensification carried beyond the limit to which this kind of mapping, on areas of low developmental potential, should be applied. Having reached this stage, however, as far as *soil* is concerned there is no departure from the old recognized great soil group and soil family form of mapping. In practice the significant features governing mapping units in this area are cultivatability, moisture absorption, and moisture storage capacity within rooting depth of any crop in the soil profile. This may not, of course, conform to a pedologic soil group specifically and is far removed from the land system concept. But in a modern view, the mapping unit should be based on these features.

The land system form of classification and mapping has recently been applied to a long-settled area of established use (Story, Galloway, and van de Graaf 1963) in the Hunter River drainage basin, New South Wales. This does not seem as happy an application as in the reconnaissance of north Australia, and in its broad form does not appear as useful. It is, of course, debatable what level of reconnaissance is worth while to prepare the way for more intensive studies. The Hunter valley survey was aimed at being a final summation of the land, not a reconnaissance, an example of how efficiently this kind of area should be mapped other than as a soil study. But in the present case a strong emphasis was placed on soil definition and classification as presumably it was considered a dominant feature. It is by way of a challenge to the soil survey approach and it does not seem to have provided anything better. In the case of an area of old farming land with a long agricultural history, the soils have to be mapped in appropriate and specific groups, certainly not great soil groups any more than detailed soil types. It is thought if one wants to come out of the general geomorphological atmosphere of the land system into refined units suitable to agriculturally stable land the modern soil survey is the answer.

Some of the most difficult and arduous land surveys have been performed by the CSIRO Division of Land Research in New Guinea. The state and progress of development, including population, have called for greater information on agricultural potential at selected points thought to be worthy of study. Seven surveys totalling about 25,000 sq miles in extent have been carried out between 1955 and 1965, in country ranging from mountain highlands to coastal plain. The land system mapping principle was taken direct from the north Australian work. The mapping has produced a great deal of new scientific data.

One interesting feature has been the recent substitution of detailed examination of selected focal points with interpolative linking, in place of the normal continuous ground traverse. In country with very few roads for transport and few adequate foot-tracks, helicopters have been used for carrying the field team and their equipment to spots which on study of aerial photographs appeared to be useful working points. These, of course, are governed by terrain for the helicopter to operate on and the maximum travelling distance for the fully loaded machine. A highly intensive study is made by the specialist scientists of the field party of the vicinity of each site for whatever distance may be humanly possible on foot. This affords the tie with photographic detail and the basis for wider interpretation of the latter. Probably soil character is the one thing most difficult to extrapolate and this is the weakness of the technique as far as soil survey is concerned.*

The survey by helicopter transport is naturally expensive, which has to be balanced against the urgency of demand for survey data and the practicability of achieving reasonable reliability in extrapolating soil information obtained at a limited number of focal points to portions impossible of access. Any system relying basically on vegetation association and land form, which are most readily studied on the photographs, is subject to correction as soon as soil becomes a principal consideration.

The Ecological Land Survey

A system of land mapping standardized by the Soil Conservation Authority of Victoria demands special consideration (for a full description see Gibbons and Downes 1964). The Authority bases its surveying on the idea of land, not soil, units. All those who deal with soil in a practical sense, whether conservationist, silviculturist, agriculturalist, or farmer, are forced to consider the land as expressed in its soil and environmental features. This is the basis for the geographic approach to classification used in conventional soil surveying. Surveys may then logically be based on what is considered the most significant factor(s) in defining land groups. This may be the soil itself but frequently it is more likely that topography, land form, drainage, geological parent material, natural vegetation, or even erodability may be of equal or

*It is understood that advanced techniques of aerial photography for defining ground character are in process of research and experiment in America; their applicability to reconnaissance surveys in Australia is being examined by the CSIRO Division of Land Research.

greater importance. The Victorian approach has not put these in any order of priority for consideration and over all has superposed a climatic control.

There is a very great deal to be said for a parallel study of seasonal moisture regimes, as has been recognized in many earlier survey publications which have used various systems of calculation. Taking Australia as a whole, water is the dominant deficiency in controlling production and the water regime of any unit of land is specially important. The evaluation of climate in terms of rainfall distribution and availability and evapotranspiration becomes a basic question in land use. Those using land survey systems have particularly emphasized this (see among others Gibbons and Downes 1964).

Gibbons and Downes make the point that communities of plants and animals in any area are controlled by the four soil-forming factors of the environment - climate, biotic agencies, relief (with drainage), and geology. The study of the principles governing the ecological stability of a region by defining areas with similar problems of environment gives the key to land mapping. This in essence is to delineate areas where the above factors are, within the limits set for them by the surveyor, effectively significant for potential forms of land use. Any factor or combination of factors may exercise the overriding control and each one is dynamic. The surveyor of land has to decide which base to use as the key for separation. To some extent this is set by the relation of the survey to an existing, or finitely proposed, land use. Any radical changes in use lead to re-survey or at least re-mapping of the constituents of land systems, for example as affected by erosion hazard under new use. Experimental work on a crop is specific to the land component but if land use becomes different, for example necessitating more and regular cultivation, presumably the boundaries have to be reconsidered.

The Victorian Soil Conservation Authority surveys have made principal use of four mapping categories, in ascending order - the land component, land unit, land system, and land zone. The land component is the basic detailed unit distinguished. By definition it is an "area where climate, parent material, topography, soil, and vegetation are uniform within the limits significant for a particular form of land use" (Gibbons and Downes 1964). Age may be important, for example in influencing organic accumulation, leaching, or acidity. The microclimate and topography may govern changes in vegetation of all types. These features are usually exemplified in the soil morphology, but the land component is mapped on different grounds from the conventional soil type and may be more inclusive. At the farm level nothing wider than the component is applicable.

The land unit embodies a collection of land components occurring in a repetitive pattern over an area of similar land forms and environment. It is claimed to be a useful working unit in separating an area into characteristic portions, particularly if it has a good rainfall and potentially wide use. The land unit gives an assessment at a district level rather than the farm level, intermediate between the land component and the land system which is composed of several land units as constituent parts. The latter is defined on a broader sweep on the same basis as the other units as a recurring pattern of topography, drainage, soil, vegetation, and geological parent material. It should again be emphasized that in all the categories no one environmental or soil factor necessarily predominates in determining the particular unit. The soil surveyor at least made by order a soil map; the "land" surveyor can relegate soil if necessary to a minor place.

The fourth and broadest unit is the land zone composed of constituent land systems. It may be set up as a primary step, for example separating smooth topography, basalt flows, deeply dissected sediments, and wind-blown coastal dunes and sand plains. Or it could be formulated by aggregating land systems when a pattern for these emerges as surveying progresses. Indeed, it seems all the categories can evolve upward.

The land unit has features in common with the soil association except for its broader concept of environment and its aim directed at land use. The soil association is a less "applied" group but it should be easy to pass from a good soil association study to a land unit map and vice versa. The Victorian system gained some inspiration from the survey of the Kowree Shire, Victoria (Blackburn and Gibbons 1954) and was linked to the land system, first defined as a mapping unit in north Australia by Christian and Stewart as early as 1946. The latter was broader in concept, very largely based on geomorphology, and perhaps, under arduous surveying conditions, could scarcely have the refinement of the Victorian usage applied to old-established farming country. There are times when the land survey on an "ecological" basis is straightforward, where for example parent material or other factor is dominant or only a restricted form of land use is practicable. But it can be readily envisaged that a great deal of personal judgment may enter, as when landscapes are changing and environmental factors are severally altering in emphasis. Soil is a much easier specific to map by, as the eyes have not constantly to be fixed on land use for deciding classification. It is necessary (as inferred by Gibbons and Downes 1964) for the surveyor to think constantly of potential productivity, yields, stocking rate, cultivation methods, plant species, fertilizers used, economics, erosion hazard, present erosion, which by mental computerization may produce a range of different personal verdicts. On the other hand if the separation of units is made on simpler grounds and the above features superposed, though sometimes causing minor alterations in assessment, the survey is less a problem. The soil survey does this and perhaps it is less material that the ancillary features mentioned sometimes cut across boundaries.

The land survey has come to stay. Whether it will replace much of the conventional soil survey remains to be seen, but it is an approach to be weighed. It does seem possible that if, in a specific area, there is any room for a variable basis of classification, it is conceivable a number of different but valid map separations due to emphasis on different factors could be made. The judgment of the surveyor must enter, for example as to whether he can, by available information or research, determine the significance of the age of basalt flows and pedogenesis or fertility and hence use them as the basis for land systems. If botanically inclined the analysis of associated vegetation may be sought as a clue for separation, even if it often does prove a less reliable support. The more variables there are on which to base a classification, the more complex the definition of units can become. The soil surveyor simplifies the process by pinning his approach to the soil profile and the topographic land form. However, there is a place for both kinds of surveys geared to the environment and conditions and to the objective.*

Land Survey through Agricultural Use

The South Australian Department of Agriculture has standardized a type of soil mapping, working in reverse as it were, from data on agricultural use (French 1958; French, Mathieson, and Clark 1968). In the region set for mapping the approach is in three stages. Initially data on crop yield, animal production, and problems associated with these are assembled from cases investigated by agricultural advisers and from farmers' records and observations. In an approximate way the soil is noted and related to production on all farms visited. The data are plotted on maps and, in the course of some years, the occurrence of conditions affecting production begins to shape itself on the map. In the second stage areas with the same problems, the same productivity, and the same suitability for a particular crop are found to be definable and boundaries may be sketched with the aid of field observations, farmers' records, and experiment plots. Up to this point soil has not entered as a prime feature and in the third stage an extensive reconnaissance of the soils and the landscapes is undertaken using the accumulated data and aerial photographs as working aids. The type of relief and the land form are introduced due to their potential effect on wind and water erodability and limits of cultivation. Finally the soils are related to great soil groups, but to make them more useful these are broken down descriptively into variants. For example there may be sandy, loamy, or clayey red-brown earths according to surface textures and these may be nominated as being associated with any one of the following: undulating to hilly country with few rock outcrops, undulating to hilly country, rounded hills and flats, or moderately undulating country. Agriculturally these units become more significant

**Terrain classification.*-Though not dealing with soil survey and field pedology, mention should be made for completeness of the recent approach to land mapping for engineering purposes by the CSIRO Division of Soil Mechanics. This has been termed terrain classification and is described in detail by Aitchison and Grant (1967). The principles of the agricultural land system were modified by engineers to take account of features elevated in importance because of their engineering significance. The engineer has predominant interest in topography, contours, depth of soil to bed-rock, classification of earthen material by the Unified System, constructional material, while he has the smallest concern with surface soils, fertility level, pH, water storage and availability in the profile, which mean everything to the agriculturist. There are, of course, exceptional cases on both sides. Land system and terrain categories, each four in number and largely equivalent, taking into account the objectives of each, might be worked out for any suitable area by a scientific team of appropriate composition.

when it is understood for example that the "sandy" red-brown earth on hill slopes is a solonized form and in consequence, with its coarser A and prismatic structured B horizon, has a gully erosion problem which is much more real than in some other red-brown earths. Indeed, this may well have been one of the agricultural problems initially noted and mapped as a significant feature.

The soils are mapped in associations of the usual form involving a dominant and one or more minor soil groups, as for example:

Moderately undulating:

Dominant: loamy red-brown earth

Minor: sandy red-brown earth, clayey red-brown earth, calcareous loam, loamy mallee soils

The map was not compiled initially from soil observations, though it finished as a soil association map. It was based first on agricultural responses, for example suitability for a specific crop: in the case of pasture, whether it was based on subterranean clover or on medics, if the land would take a long fallow or not, its potential erodability, trace element deficiencies, and fertilizer requirement; plant and agricultural features such as these were tied to soil characteristics for final mapping. Stock health and production were also included.

The system applies to established farm land with a history of land use. It also needs a community of intelligent farmers to cooperate in experiments and provide basic information as well as applying recommendations of advisers. Finally it needs a stable form of land use, as in the recent survey of French, Mathieson, and Clark (1968), where cereals and clover/medic-based pastures were growing. It cannot for obvious reasons be applied properly to sparsely developed country or to new land with a short agricultural history. It is essential to have enough statistical data on crop yields of all kinds and animal production in the district and full climatic details to assist in understanding water regimes.

As a final comment the South Australian system is a land survey precisely like the Victorian though with differing emphasis on some features and, of course, in approach. It is thought a good deal could come from joining the two to make land surveys. The Victorian, for example, seems to pay more attention to climatic effects on moisture regime, the South Australian has a very strong agricultural base. It will be very interesting at some future time to compare a map of the lower south-east of South Australia with that of the adjoining south-western region of Victoria (Gibbons and Downes 1964).

Land Classification by Land Surveyors

Land classification as a base for subdivision and settlement dates back to colonial days. A good deal of skill was developed by land surveyors in valuing new country and most of the irrigation areas of New South Wales were defined and the soils classified by them. The land classes they used were flexible and were relative to each other in a region but there was no constancy in standards between regions. In each State the Department of Lands was the responsible body for selecting land and initiating settlement and this policy continued generally until specialist soil surveys began expanding about 1930.

In Western Australia the right to classify land has been maintained to the present day. The old arbitrary classes for land ranging from Class I through to Class IIIC are now modified wherever arable agriculture is proposed. In the type of country now being opened for settlement, the collaboration of the soil scientists in the Department of Agriculture is sought. The Lands Department surveyors thus have the advantage of the classification standards suggested by agriculturalists, which are of the type readily followed without specialist qualifications. For example, on the Esperance Plain the groupings could be based on simple features such as depth of sand over a clay layer or degrees of gravel concentration in surface soils. Since productivity in these low-fertility soils is dependent on application of fertilizer the main consideration is water availability in the profile and its seasonal reliability. Further from the coast in this region the salinity factor enters but in all it can be made sufficiently straightforward for setting up soil groups for field classification and mapping by the land surveyors.

Land classification of this type is applicable to new developing country with simple soil patterns definable on a limited number of morphological features, topography, and vegetation. It appears adequate as applied currently to development of new land in Western Australia, but it is not accepted or sought in other States. However, with the decline in numbers of trained soil surveyors generally in Australia the systems used need to be simply devised for application by ranks of lesser competence in working out soil patterns. This is dependent on the amount of background information available on productivity and on problems in a region and with a view to a restricted system of land use. Land classification of this type can only be built satisfactorily on the prior results of investigation at an experimental station in the region dealing with the main soil types and subject to climatic controls especially touching the marginal lands of Western Australia.

Land Capability Classification

Soil conservation work in Australia as in America has paid attention to suitability of land for use at different intensities and the limitations controlling it. Queensland has used the system recently for field mapping, employing the same eight capability classes as the United States Department of Agriculture, but superposing an array of 15 limiting features which, singly or in combination, may lower the grading of a soil. This makes the classification more precise although a number of the features would be automatically involved initially in grading the soil. The limitations used by the Queensland Department of Primary Industry are susceptibility to water and to wind erosion or erosive flooding, steepness of topography, microrelief, stoniness, physical properties of soil causing difficulty of cultivation or affecting plant growth, wetness, salinity, depth of solum, water-holding capacity, fertility status, and climatic factors. One or more of these operating against a prescribed use would lower the classification from one to three grades. The criticism of such land capability classification is that it does not take sufficient notice of the nature of the soil itself, as for example by assuming all class I land is nearly level, or that steepness is correlated inevitably with erodability, or that only soils more than 36 in. deep can be class I. However, land capability is really what soil survey should indicate and surveys are made to check on the limitations of soils to kinds of use.

But for many purposes of extensive agriculture, broad "land" groups are used. For example one group might read, "Dark self-mulching and cracking basaltic clays of moderate depth on gently undulating plains with some linear gilgai". This is the principle used by Isbell (1962) in setting up mapping groups in the brigalow country, and it is parallel to the kind of unit used by land surveyors in land classification in Western Australia mentioned previously. It is also a "land unit" in the terms used by the CSIRO Division of Land Research. Probably this grouping is all that matters. It is different when more information is needed on soils in relation to plant growth.

The Queensland workers have studied suitability of soils for growing tobacco and have reduced requirements to the permeability properties of the profile. Water is not limiting and heavy fertilization is normal which eliminates features otherwise more significant elsewhere. In assessing some areas proposed for irrigation and mapped in land units, the Northcote system of classification has been superposed. This does not go far enough because it does not identify soil groups in terms of suitability, or limitations, for irrigation, quite apart from any question of crop type. The difficult problem always lies with border-line cases on which experimental work is the only guide.

In all their work the Queensland soil surveyors are aiming at land capability, and mapping in soil units as such is less important. Their approach could be compared with Western Australian land classification mentioned previously.

Summary of Soil Survey Usage

Outlooks on soil survey in Australia are governed by the type of country examined, its problems, and its uses, whether extensive or intensive, and workers tend to see the field attack as involving a specially applied or devised procedure. In some cases this is true but, on balance, more uniformity might be sought. The Northcote classification is becoming more widely used and it has a chance of providing a common link for Australian work. All over the world pedologists have talked about the special features of their soils and the difficulties of classification and it is not surprising this tendency exists in the States of Australia, which have such widely divergent agricultural experience and development. It is regrettable that virtually no overall comparative study has been made of the validity of the differences in thought on surveying held by different organizations and in different parts of Australia.

The soil survey position in Australia today runs along the following lines:

States

Queensland.-Mapping by land units and land capability classes, with side use of the Northcote soil classification system.

New South Wales.-Experimental attempts to use layer (ground surface) mapping in fertility studies; a small amount of conventional soil type mapping in irrigation areas.

Victoria.-Conventional soil type mapping by Department of Agriculture; land system - land unit mapping by Soil Conservation Authority.

South Australia.-Land classification and soil mapping combining climate, topography, and subgroups of great soil groups.

Western Australia.-Land classification based on broad soil groups defined morphologically and on salinity status.

Commonwealth

CSIRO Division of Land Research.-Land system surveys at various levels of detail.

CSIRO Division of Soils.-Divided between mapping by Northcote classification system and soil associations of varying type usually based on subgroups of great soil groups and/or related to ground surfaces or surfaces of different age.

Department of Primary Industry.-Land system surveys with side use of Northcote classification (for northern Australia).

This rather diverse, if not confusing, approach to soil survey in Australia, which has largely developed in the last 10 years, is not very satisfactory. In Section VIII an attempt is made to set out a workable plan.

VI. SOIL SURVEY AND PRODUCTIVITY RESEARCH

As a consequence of the criticism of the usefulness of detailed soil survey for application to productivity, it was necessary to think about a satisfactory alternative. Soil surveys, apart from pedological research programmes, are wholly utilitarian and a link with land use and soil fertility should be sought. B.E. Butler (private communication) has put this very well: "The impulse to make a soil survey is to answer the question - how can research data on a soil be extended or adapted for the range of soils across a region? This challenge can be broken into two parts: (a) What factors govern growth response in a particular case? (b) How do these factors vary across a region? Relatively little work has been done on the first and perhaps none on the second, because soil types as defined in the past have not been correlated with the soil features which may have been indicated by (a)". As stated in Section II, the correlations made were done on the basis of analogy and comparison and by massive accumulation of field observations. The United States survey, with its practice of estimating productivity rating, was doing much the same, but was partly at least backed by field experiments. Australian workers rejected the productivity rating according to any of the United States or Canadian systems and based recommendations on "informed" opinion. Very little indeed was done by agronomists or soil surveyors to bring together scientific evaluation of soil fertility from their respective sides. It is not unfair to say the surveyor, while claiming an opinion on productivity, did not attempt to prove it by experiment and the agronomist, claiming to solve fertility problems by experiment, failed to understand the significance of the soil profile.

In more recent times the pedologist has realized soil fertility is basically a soil, not an agronomic, problem and fortunately has begun to attack it. The question he has asked is what are the controlling properties in a soil profile linked with maximum productivity when an adequate supply of major nutrients is present? As a corollary, what morphological features in the soil profile correlate with those properties so that field observation, with or without rapid field tests, can be used to define a soil unit - or "soil type" in a specific sense - for land use purposes? Such correlations do not make an unreasonable assumption especially as physical attributes frequently characterize the relationship, as for example under irrigation, or are associated with trace element deficiencies.

One of the first to seek such a relationship was Cockroft, working with peach trees under irrigation, who asked what features are common to soils in the Goulburn valley, Victoria, with a high productive capacity for peaches? His conclusion came down to simple terms for the riverine plain of northern Victoria (Cockroft, Bakker, and Wallbrink 1962). It was a medium-textured A horizon approximately 10 in. deep, over a clay B horizon of sufficient permeability to prevent waterlogging of the surface soil for more than short periods. The key to these conclusions was that the active feeding roots were concentrated within a friable layer on the average not more than 10 in. deep except in very well-aerated soils.

Butler (private communication) elaborated this theme, arguing that not only should similar prescriptions be obtained for other crops but that the soil itself, not soil treatment, should be used as the variable in comparative studies. Instead of subjecting an assumed uniform soil area to varying treatments, chemical and physical, reverse the procedure and apply the same optimum treatments to different soil areas. By so doing the controlling features in plant response may be identified. Agronomic data may be tied to soil differentials and in consequence to application geographically. Butler (see Section IV) insisted that the existing concept of a soil type had no reality in itself as applied to plant growth and for plant response to treatment. The thesis is that, for the determination of plant response, it is impossible to define boundaries accurately on the traditional soil type basis in very many cases, that the use of soil complexes for unmappable variability of soil types is self-defeating, that anthropic changes after long periods of development counter the system, and that the native ecological factor used a great deal in the past, is not now regarded as well correlated, even if the vegetation exists.

Loveday (1962) has attacked the problem in the field by the so-called small plot technique, originally proposed by Butler (unpublished), and parallel pot experiments under fully controlled conditions in the glasshouse. He deliberately set out to try and establish correlations between yield and soil properties and to link the significant ones with morphological features of the profile. He used lucerne as the test plant in multi-replicated, one yard square plots under rigorously controlled irrigation. It was not a particularly successful venture, partly because of the poor soil medium (grey and brown soils of heavy texture), with an extremely low infiltration capacity and restricted depth of wetting.

The array of chemical and physical properties tested for correlation with yield and between themselves reduced to two parameters - exchangeable calcium content in the 1-4 in. layer and the sodium chloride content in the 8-12 in. layer - as having significance. The key to application of this work is the reflection of the significant properties in observable morphological features, and this proved only a rather crude relationship. The main feature was a slightly greater surface cracking in the darker-coloured soils and hence potentially better water absorption affecting the supply available to plants. Much more experimentation is needed over a wide variety of soils with different topographic and micro-environmental characteristics before any conclusion could be drawn on this approach. But the important point is that it was aimed at finding parameters for a new kind of mapping unit for surveys, which would be significant for plant growth to replace the old soil type, considered to be inadequate.

Others have done a great deal in testing the fertility characteristics of soils using more conventional groups. B.E. Butler (Taylor 1950) for the Riverine Plain made an effort to group conventional soil types, mapped in surveys into a limited number of classes related to their presumed suitability for growing specific crops and to the water relationships of their profiles under irrigation. This was, of course, informed guesswork based on a considerable amount of observational data. It was an application of accumulated experience for the Riverine Plain similar to that Northcote (1948) had used in the Murray valley for irrigated horticultural crops (see Section III). Butler employed colour names to distinguish the groups, referring to green or yellow or purple and so on soils. The colours were simply those used in colouring maps as a guide to potential land use. It would have been possible to do this kind of mapping in the field eliminating soil types as individuals and there is no real objection to doing so when, firstly, a set array of crops is decided on in developing the land under irrigation and, secondly, the surveyor has sufficient data from accumulated comparative observation or has the backing of field experiment. However, it was a realization of the fallibility of guesswork and the number of assumptions being made on the key characteristics of soils affecting plant response, which drove Butler to urge a direct attack on the problem. Loveday's work mentioned above was the initial attempt. Certain it is that much more needs to be known of the features of the soil profile conducing to optimum growth and maximum yield. It is not enough just to grow a plant. The two points to be raised for future surveys, particularly of new land, are: Is the soil type the correct unit? Can the field work be done differently and soundly for the requirements of the farmer?

It might be expected that soil - land use features would continue to be specially important in irrigation areas. As it happens, very little work in detailed survey compared with past periods is currently being done in Australia. The most recently published surveys of the Victorian irrigation areas, e.g. in the Swan Hill district (Skene and Sergeant 1966), in essence had followed the conventional soil type method with some consideration of the principle of ground surfaces applied to the dune landscape, as outlined earlier by Churchward (1960). However, the 40 soil types and phases regarded as partly or wholly suitable for cropping have been aggregated into five groups according to suitability for a range of horticultural and fodder crops. The maps are coloured simply as these groups, depending on an assessed usefulness of soil types and phases. The types have been put in three grades - good, fair, and doubtful (i.e. poor unless under skilful management) - as an indication of preferable land use. Thirteen crops embracing citrus, stone fruits, prunes, vines, fodder crops, cereals, and pastures were considered in the assessment. Salinity was included as a complicating factor in grading the soils. Detailed specifications were given for the key features of the five usable groups of soils. Such correlation has been possible through the vast amount of available experience and data on the use and productivity of these soils over periods of up to 40 years.

The New South Wales surveys recently have been of new land for irrigation development (Stannard 1962) and have employed a rather vaguely defined land classification. The factors considered relate to: soil character, both of the upper and deeper horizons; topography in regard to slope, elevation above or below general landscape levels, and topographic position as to water shedding, receiving, and ponding; stratigraphy referring to permeability of D layers below the solum proper. The integration of these factors affords the basis for classifying the land for irrigation development. In practice they are assessed by the skilled surveyor and it would be possible, if the parameters for soil character were specifically defined, to map an area directly by such classes. Stannard (1962) reduces the actual classification to four categories for horticultural use: suitable; suitable with artificial drainage; marginal, requiring specifically adapted crops; unsuitable. The system is straightforward but quite subjective and it lacks definiteness in using general terms such as "relatively permeable". It is necessary to define parameters with precision if any classification system is to be used by less experienced surveyors.

Workers in Queensland also began to test the properties of soil groups defined in the field both in the glasshouse and by analysis (Fergus 1962). Were these morphologically separate types different or not for plant growth? Can preliminary laboratory tests prove the soundness of the field classification of soil units proposed from reconnaissance surveying and establish them for more precise mapping? It seemed that this was possible at least for some types of land use such as cereals and small grains. The pot experimental work used the subtractive technique for nutrient deficiencies and the range of available water in the profile as a physical measurement.

The same principles were followed in the study of soil groups in the Dorrigo district, New South Wales (Spencer and McArthur 1962). What does transpire in much of this work is that variations in plant growth and associated nutrient deficiencies are almost as great for replicated test sites within a single soil type or group as between different ones. This is quite understandable when land has been farmed for a long period or in new land recently cleared. As examples, the former case is affected by the form of past fertilizer practice or by erosional loss or by management and in the latter case variation may be due to localized accumulations of plant ash. However, if this state of affairs becomes evident, no mapping unit can be devised to cope with it economically. The foresters recognize the conventional soil type as a "poor measure of site quality" for planted pine trees (Hamilton 1962). Some very detailed studies have been made of the variability in plant growth within a single soil type and there does not seem to be any escape from the conclusion that it has an unreliable relationship with fertility. Chemically, of course, this has also been shown, as in pH variability over short distances (Raupach 1951) and available potassium ranging widely at sites close together in the same field (Graley, Nicolls, and Piper 1960).

So the whole future of the correlation of a soil mapping unit and plant response remains obscure. From a consideration of the work that has been done three points emerge. (a) The significant aspect so largely controlling (non-irrigated) plant growth is the physics of the soil and the soil moisture regime. Hence the importance of texture, structure, and stability of surface soils, porosity and permeability of subsoils, water storage capacity of the root zone, site and drainage characteristics affecting absorption and internal seepage on slopes - these are the kind of things to look for. (b) The plant nutrient content of the soil and deficiencies in it are frequently notably variable and for mapping purposes may only be relied on for clearly divergent soil "types". Otherwise there seems to be no alternative to a programme of analysis of samples by specified techniques such as are widely used in Europe and America. At the present time in Australia multiple analyses, particularly for phosphorus requirement, are becoming more widespread and this in itself points to the lack of an effective mapping unit for fertility purposes. (c) Correlation of soil and plant growth in more general form is more evident when dealing with major groups of soils than in detail with the soil series or soil type. In the case of newly developed land in Queensland this seems to be practicable for some crops at the sub-great soil group level. For anything more intensive a precise system has to be evolved.

Currently it is far from clear how far pedologists will go in the study of soil fertility and estimates of productivity of an, at present, undefined soil "type", and conversely, how far agronomists will go in introducing the soil profile into their approach. There is no reason why the study of McArthur (1964) on the fertility characteristics of the western Dorrigo plateau, New South Wales, or of Fergus (1962) on the brigalow lands in Queensland should not be extended by other pedologists where conditions are suitable, or why the close association of pedologists and agronomists in field experiment in Tasmania should not be applied in practice elsewhere. There has been far too much compartmenting of effort - pedologists defining profiles and types, chemists in laboratory and glasshouse studying fertility levels, and agronomists working in the field and by pot experiments, all as separate investigations. If the present decade saw an integration of effort for statistically based studies on some mappable soil unit relating to plant growth and response it would be an enormous advance.

In considering this relation of soil properties to plant response it seems that only statistical treatment of data will reveal the permissible range of a specific property before it becomes limiting.

For many properties this may be so wide that any attempt at precise definition is useless. The Northcote system of soil classification and mapping (Sections IV and V) is a simpler form dealing specifically with the physical profile and morphological features observable in the field. Since soil moisture regimes are the key to a great deal of plant response in Australia this approach comes closer to requirements but it has never been tested experimentally or by statistical study of field observations. The Butler and Northcote concepts are basically different but whether the latter can be applied in finer distinctions by further subdivision of units is still open to study. To arrive at the unit with correlated profile properties and plant response, a beginning has to be made with identifiable profiles. Northcote's principal profile forms may possibly be a convenient starting point to evolve a new unit.

VII. THE RISE OF RESEARCH IN FIELD PEDOLOGY

The number of those skilled in field pedology has been limited. The majority have worked in CSIRO, principally in the Division of Soils, but others have ably contributed. Of these the school of pedological study inspired and developed by E.G. Hallsworth between 1940 and 1950, particularly after World War II, has been notable for its range of work on the character and genesis of the great soil groups occurring in New South Wales. The series of eight papers by Hallsworth and his associates is a valuable contribution to Australian pedology over a wide field. Their studies covered, for example, the alpine humus soils (Costin, Hallsworth, and Woof 1952), the ironstone soils (Hallsworth, Costin, and Gibbons 1954), and also included papers on gilgai soils and basaltic soils. No similar set of investigations of the field and laboratory aspects of Australian great soil groups has been made in such a short period.

Field pedological research advanced considerably, concurrently with the slowing down of soil surveys after about 1955. It has always been a basic, if rather a background, feature of the field work all through the period of surveying. The later work tended to grow out of earlier research, but had more breadth and vigour. Research of this kind calls for training, experience, and an original perceptiveness not given to all field workers. It is not practicable here to cover all Australian investigations in field pedology or to give more than limited details of any. What is attempted is a brief review of the development of this aspect of soil research along several selected major lines with an indication of their importance and impact on more applied studies.

The Continental Soil Map

The inspiration for much of the pedological research lies in Prescott's (1931) "Soils of Australia in Relation to Vegetation and Climate". This introduced Australian pedologists to the principles of classification of the Russian school, then being stressed also by C.F. Marbut to the soil surveyors of America. Highly significant for pedologists was Prescott's soil map of Australia based on the principles set out in the same publication. This was one of the earliest soil maps of a continental area in the world and was compiled with the close study of all available data on soils and interpreted in the light of climatic influences and the associated vegetation. It made Australian pedologists aware of international great soil groups as classification units, at the same time defining several new Australian ones. The map with its 10 soil groups could only be an elementary beginning because of the lack of data and experience with Australian soils, but its great value lay in turning pedologists' eyes from the close environment and detail of intensive surveys of small areas to wider horizons, so necessary if the soils of a continent were to be seen in pedological focus. It is impossible to overestimate the influence and significance of this piece of pedological research to later Australian workers.

Later Prescott (1944) published a second soil map of Australia with 18 soil groups. This added more detail with more presumed accuracy of boundaries, not that the latter means much when reproduced at a scale of 1:10,000,000. The second map in the meantime had the advantage of larger-scale maps on a similar basis by Stephens (1941) of Tasmania and Teakle (1937) of Western Australia, of a scattering of soil surveys through southern Australia, and the studies of Whitehouse (1940) on laterite in Queensland.

Stephens (1952, 1956, 1963) carried on the work of soil classification at the great soil group level for Australia and finally produced a third continental map at an enlarged scale of 1:6,000,000. The number of groups recognized increased to 47. Stephens had tremendously greater sources of information and accumulated data to draw on and the soil map as now reproduced possibly represents about the limit in this type of mapping likely to be attempted, at any rate for a long time. Nicolls and Dimmock (1965) have since published a more detailed great soil group map of Tasmania at a scale of 1:1,800,000.

A word should be said of these continental maps, about which there seems to be a measure of misunderstanding. They have no precise utilitarian value and are not applicable to agricultural use even at regional levels. In Australia in the southern portion with a long agricultural history this is quite clear, but in the less-developed parts which depend on native pasture, the key to grazing productivity is vegetation, which is not well correlated with broad soil groups, even if boundaries could be conveniently mapped. The great soil groups used have not a working relationship to land productivity. The spectrum of soils in each group has a population with diverse physical and even chemical attributes so that, collectively, they can give only a very broad-scale catalogue of soil resources. They must be viewed as a means of comparison with other continental areas, as far as agreement can be reached between compilers.* At present within Australia Stephens's (1963) classification of great soil groups is generally used, with qualifications, as a standard reference; other systems and terminology have only

*Previous world soil maps have shown errors and the difficulty of international comparison. It remains to be seen what will come in the new world soil map being prepared by a representative committee of pedologists under the sponsorship of F.A.O.

limited currency. Hallsworth, Costin, and Gibbons (1954) endeavoured to substitute alternative names for the podzol-podzolic soil group. Pedologists generally have preferred to use the old terminology, e.g. grey-brown, red, yellow podzolic soils, rather than the names of leptopodzol and amphipodzol proposed. A weakness in great soil group definition is the absence of recognized code of practice in soil taxonomy.

Having made all these negative points we should not overlook the merit of the continental soil map as a general picture of soil resources, mapped in the only available classification category that can be conveniently used and that has currency in other countries. Nor should the usefulness of the category of great soil groups be written off, as it still gives working approximations - pigeonholes, even if loosely defined, for placing soil units - and is a means of communicating impressions of soil morphology. It also conveniently allows the definition of subgroups of the main group with more reality as mapping units. The great soil groups currently recognized in Australia are used by all field pedologists in practice for broadly characterizing a soil profile. Until an improved system is devised and accepted, they do conveniently serve for purposes of reference. They are useful as long as pedologists can agree on a picture of the meaning of genetic processes, such as podzolization, solonization, and so on, as expressed in profile morphology. The system has deficiencies, and it is a subjective approach to classification, but the present author would regret its passing from pedological currency without a clearly improved alternative.

Investigation of alternatives to the great soil group approach for continental mapping has so far resulted only in the classification key of Northcote (Section V) by which a new soil map of Australia has been prepared. It is a notable milestone in such mapping. It is noted that Nicolls and Dimmock (1965) in their recent soil map of Tasmania extended some great soil group units into subgroups as "gradational" and "duplex" forms.

The Solodic Soils

Solodic or, more precisely, solonetzic soils were first shown by Prescott (1944) on his second soil map of Australia, by which time observations during surveys had been made of the occurrence of solodized solonetz soils with their characteristic domed columns (Burvill and Teakle 1938). These with a few exceptions were restricted in area and generally the term podzolic was applied to such zones in an overall manner without distinction. In this way, Prescott had shown the broad sweep of soils inside the Dividing Range in Victoria as podzolic types. Downes's major contribution to Australian pedology was his recognition during his surveys in Victoria (Downes 1949) of the solodic soils existing there and of their pedological significance.

One particular feature of certain hill slope soils at Dookie, Victoria, was their liability to tunnel erosion, which involved mudflow of a highly dispersed subsoil clay, leaving subsurface tunnels into which the overlying soil later collapsed. The clay was high in exchangeable sodium, low in calcium. These profile conditions are significantly widespread round Australia and Downes should have the credit of having recognized them as solodic, as well as of extending their observed range of occurrence in the same climatic belt. His theory of formation (Downes 1954) rests on the occurrence of arid cycles in Pleistocene to Recent times, during which there was a considerable accession of cyclic salt, windborne from marine or terrestrial sources. The subsequent rainfall was not sufficient to remove the salts quickly, so that partial leaching transformed the salinized soils to solonized forms with drastic effects on the nature of the clay B horizon and its associated cations. At present 20-30% of the cations are sodium and 20% or less calcium, with magnesium remaining dominant. This condition is typical of solodized solonetz soils and any more recent increase in rainfall has not been sufficient to alter the cation balance.

The solodic soil is a problem when disturbed, though under good pasture cover it resists erosion through its compacted surface. Gully erosion is probably the most widespread failing. Dam construction or contouring on slopes with these soils requires special care to avoid tunnelling or piping due to the dispersion of the clay on saturation. The soils have been described and their continental extent mapped by Northcote (1960-68) and Stephens (1962).

The related solodized solonetz soils have been studied by Hallsworth and Waring (1964) with the presumption that soils of this character, and solodic types also, could arise without the prior development of solonchaks and solonetz types. Since the area of their investigation could not have been exposed to cyclic salt or any other massive supply of sodium chloride, the authors put forward a hypothesis based on five prerequisite conditions: a climatic environment preventing accumulation of organic matter in the soil; a coarse-textured parent material capable of allowing mechanical migration of clay to form a fine-textured B horizon; a parent material low in exchangeable calcium; a kind of vegetative cover taking up soluble silica from soil water and returning it in leaf litter; a source of sodium ions to create a partial sodium saturation of the illuviated clay - this was thought to be rain water with a positive imbalance of sodium and calcium.

The hypotheses of Downes and of Hallsworth and Waring form an interesting base for future pedological research with this soil group.

Soils of the Mallee Zone and South-east of South Australia

The great contribution of Crocker on the pedology of the soils in the South-east and the drier areas of South Australia should be fully appreciated. His key paper (Crocker 1946) principally set out his hypothesis on the polygenetic development of soils and their relation to land forms, on the origin of soil material, and on the chronological relationship of soil formation and physiography to Pleistocene and Recent geological history. We should pay a tribute to the brilliance of his observation and interpretation over a short period of only a few years, in this palaeopedological study which has greatly influenced the thinking of pedologists. It does not matter at all if he was partly in error. Indeed, the surprising thing is that he saw so much to interpret in 3 or 4 years of field experience as a pedologist and under conditions of travel and accessibility very far removed from the present. It was the foundation for others to work on and to be inspired by.

Crocker's hypotheses followed three main lines which depended on the known changes in sea level associated with glaciation in the Pleistocene and the occurrence of arid cycles in Recent time (Crocker 1946). In brief, he thought there was widespread landward accession of coarser and finer sand and calcareous material from the sea floor during low sea levels in periods of world glaciation. This not only affected the immediate coastal belt but ultimately contributed a blanket of calcareous loess far inland which he believed was the source of the lime in the mallee zone. With the post-glacial rise in sea level, stabilization and leaching in the wetter areas produced deep siliceous sand over illuvial lime and calcrete; in the drier inland, solonization occurred through the presence of cyclic marine salts and shallow illuvial lime horizons developed. In early to mid Recent time one or more arid periods of instability allowed widespread denudation with the formation of broad sand sheets and the loose dunes typical of the mallee zone and the desert landscape of central Australia. The pedological history of much of South Australia turns on the climatic changes of high winds and rainfall of the glacial epochs of the Pleistocene and of winds on an unstable surface in arid periods of the Recent times. These were the principles Crocker laid down, applied particularly to the South-east of South Australia and the Murray mallee area.

Crocker's theses and inferences have been debated and questioned. Apparently he was wrong, for example, in attributing too wide an influence to wind-blown coastal sands and in his explanation, neat as it seemed, of the origin of the lime in mallee soils. But others have been able to build on the base of his ideas and of these Northcote and Blackburn should be mentioned particularly.

The Brown Solonized Soils

Northcote's principal contribution to research in this field was his reconstruction of the pedological history of the soils of present and previous landscapes for a typical portion of the mallee region in south-western New South Wales (Northcote 1951). Geologists have given accounts of the Tertiary land forms of this area and Crocker (1946) had discussed them in relation to his theory of a blanket of calcareous loess on an old surface of mature highly leached soils, which included occurrences of lateritized material. Northcote (1951) placed all this observation in a more positive light, adducing data on pedological grounds for a four-stage sequence.

First, in the climate of the lower Pliocene, the land surface was reduced to a low-level peneplain. Second, through the Pliocene under conditions of high rainfall and sluggish drainage on the flat topography, podzolizing processes actively went on combined with high ground-water levels; to these are ascribed the leaching of iron and alumina and silica and the formation of laterite and silcrete associated inevitably with very impoverished sandy soils. Northcote found widespread evidence of this buried under the present soil mantle at no great depth. Third, the Pleistocene saw some uplift of the landscape with a rejuvenation of drainage lines and considerable distribution of soil material through erosion and alluviation; the present pattern of drainage presumably emerged in an environment of acid fine- and coarse-textured soils according to the mode of deposition. In the latter part of this period from some external source (but *not* as Crocker postulated from the continental shelf) came vast amounts of wind-blown calcareous material with soluble salts from which developed, in association with the older soils, solonized profiles mostly with high lime concentrations in a B_{ca} horizon. Fourth, in the early Recent occurred one or probably several arid cycles during which, as Crocker (1946) had indicated, the whole landscape became unstable and the dune systems characteristic of the mallee and inland desertic areas were formed. Northcote proposed a series of arid periods separated by stable times to account for the differences in types of dunes* and the wide array and complicated pattern of soil types. There are, for example, the extremely patchy occurrence of greyer and browner soils at all levels, of stony layers and soils with relatively low amounts of soft lime, of loose sand dunes and of fine-textured, scarcely altered, soils in swales related to the earlier landscape before the accessions of lime.

Northcote gave a very clear chronological picture of all these stages of development of the present surface and it is the basis on which interpretation is now generally made of the soils and land form of the whole region of the ancient Murravian Gulf. It represents probably his most notable pedological work and is an excellent example of allying pedology and geology in Quaternary studies. It is also the base on which soil surveying in this region can be more rationally built as it explains the extraordinary complex of soils so often met with in the field and which frequently is not mappable at any convenient level. This is also a good case to justify prior or at least parallel studies in the principles of soil occurrence before too deeply engaging in soil survey of any type.

To complete the story of the mallee soils we should include the work of Churchward (1963*a*,*b*) on the Swan Hill, Victoria, region where he more precisely defined the set of ground surfaces developed in late Pleistocene and Recent time. This is at some variance with Northcote's thesis in detail but is an excellent deductive study of the aeolian influence in mallee soil building.

South-east of South Australia and Western Victoria

Another phase of research in field pedology stemming from Crocker's work concerning the soils and land forms in the South-east of South Australia was taken up by Blackburn. His final publications (Blackburn, Bond, and Clarke 1965, 1967) followed a long series of soil surveys in this region from 1952 to 1964, and this detailed survey, which had begun 20 years earlier (Stephens *et al.* 1941), gave him an excellent base to attack its pedology. His paper on soil development associated with stranded beach ridges (Blackburn, Bond, and Clarke 1965) is a close analysis of the processes producing the present land surface of the region and its soils, together with an estimate of its chronology.

*This was recognized in earlier soil surveys, as for example in mapping the Murray and Winkie sands.

By using pedological and analytical evidence, Blackburn showed a number of earlier hypotheses were at best doubtful. He found no evidence to support Crocker's calcareous loess theory in the region nor did he agree with Crocker's proposition that all the siliceous sand deposits were resorted material from leached shore line dunes, although this was a considerable factor. Blackburn explained the occurrence of blown sands with a wide coarse sand to fine sand ratio in the south central area of the South-east as being derived from coarse fluviatile material, associated with vigorous drainage coming out of Victoria to an old shore line. Hossfeld (1946) has suggested such a river system and Blackburn's work proposes it as part of an ancient course of the southern Murray River system. Like Hossfeld also, he concluded that diastrophism, combined with eustatic changes of sea level, accounted for the shaping of the land form of the South-east region.

But an outstanding feature of Blackburn's work was his expansion of the pattern of stranded beach ridges over a wide area to the north and the east much beyond the limit which had been set by earlier workers at the Naracoorte Range in South Australia. This opened up a new vision of the emergence of the Pleistocene land mass and carried the movement back into the Pliocene. About 30 old beach ridges in South Australia and a further 40 in western Victoria have been mapped by Blackburn (Blackburn, Bond, and Clarke 1965, 1967). His meticulously careful study of the "Lowan ridges" in the field and laboratory has now established them as ancient, stranded beach ridges. They are distinguished by age and their non-calcareous nature from the later beach lines of South Australia. They fit the same geographic arrangement as parallel ridges trending more or less north-west in a wide shallow arc in western Victoria reaching from the Glenelg River as far as the Big Desert.

A development of the stranded shore line theory led Blackburn to consider the origin of the dark clay soils of the Victorian Wimmera and westward plains. The new proposal is that, prior to the diastrophism which lifted and tilted down to the north the central western plain in Victoria, drainage from the southern Murray basin flowed to the sea close to the Western Highlands, extending, as the shore line retreated westward, through the region of County Lowan. In the sheltered conditions behind the beach dunes a variably extensive deposition, under semi-lacustrine conditions, of clays occurred, the largest being the Wimmera plain, but repeated in smaller zones to the west. The departure of the Murray system to its present position caused the establishment of the current drainage system which itself could neither have produced, nor subsequently altered, the clay plains.

The work of Blackburn on the stranded beach ridges and the clay plains of South Australia and western Victoria represents a methodical, ordered assembly of factual information confirming, adding to, and amending theory over years of research. The outlines of the pedological history of this region now seem firmly established and the details can be fitted into it. The work is a model which could profitably be carried into wider fields.

The Riverine Plain of South-eastern Australia

Vast areas of the Australian continent have been formed by combined riverine and aeolian action. The pedology of the great plains of Queensland, western New South Wales, and northern Victoria was clarified, largely in consequence of the theories and principles developed by Butler, whose attack mainly centred on the Riverine Plain of south-eastern Australia. His ideas have had widespread application and have been taken up, applied, and modified by others in most of the States.

Butler's papers (1950, 1956, 1958, 1959) set out two theories on the origin of the plains soils and a chronology based on cycles of erosion. The formation of the Riverine Plain was the result of alluviation on a vast scale in Pleistocene times during alternating arid and pluvial periods. A network of rivers issuing from the eastern and southern mountains poured out coarser and finer fluviatile material transgressing the present drainage system, which alone could not have produced the pattern of the existing plains. The principle of these "prior streams" is quite simple and its application to the sedimentary array of soils is basic in interpreting the distribution and succession of soils.

However, not all the characteristics of the plain were explicable in terms of alluviation, particularly as multi-storey profiles had been observed. The answer in Butler's view seemed to lie in accession of external material by wind action which Butler supposed was hot loess from the mallee fringe adjoining the plains on the west. This aeolian drift was called parna and represented sand-sized aggregates of clay which had already passed through an earlier pedogenic cycle. The parna blanketed the landscape during arid periods both on plains and on hill slopes. The hypothesis raised queries on the origin of a "calcareous parna" and the curious belt of soils free of it cutting across the main zone of deposition. Parna is similar to the material of which lunettes are built and theoretically has a limited range of movement, not over hundreds of miles as proposed. However, the parna hypothesis did explain the occurrence of subplastic clay soils of unique physical character, of lime and soil material on hill slopes unrelated to the country rock and on plains, yet not typically riverine. The parna principle, like that of the prior streams, has been widely applied by Australian pedologists. The argument about it turns on origin and travel of material and an adequate focal source which is unresolved.

Not all Butler's hypotheses have gone unchallenged. For example Pels's (1964) version is at variance with them over the origin of the more recent and older riverine layers. His intensive study of a stream system showed an original course and several successive derivatives from it, of decreasing vigour, so that it is not necessary to postulate several separate depositional periods. Pels has contributed a mass of data on the structure of the Riverine Plain. He also considers the parna was blown from local fluviatile deposits. It is not clear where all the lime has come from, as the riverine deposits are normally low in it.

The soil formations of the plains shown to be multi-storey, composed of riverine and aeolian materials, led Butler to the concept of ground surfaces - layers which had been in place long enough for pedogenic processes to operate. The full profile then is constituted of the most recent layer underlain by variably truncated remnants of earlier surfaces. There is, of course, an agricultural, as well as pedological, significance to buried soils and in practical soil mapping their variability at shallow depths makes soil type definition virtually impossible. Using ground surfaces, Butler developed his K (K=*kronos*) cycle principle, based on the alternation of erosional, depositional, and soil-forming periods. The thesis was that stripping and deposition took place towards the close of an arid cycle, when surface stability had been impaired through loss of vegetation, by the effect of torrential rain storms initiating a wet cycle. Stability later of the new ground surface, either stripped or deposited, allowed profile pedogenesis under a moister regime. Butler numbered these ground surfaces from K_0 as the currently forming and amorphic surface layer (if present), K_1 with a degree of profile form, K_2, K_3, etc., buried remnants of earlier surfaces. The K cycles cannot be interrelated between regions directly since there is no equivalence in time of K_2 and earlier surfaces, each sequence being relevant to a landscape with a common geomorphic history. According to Pels (1964) this interesting theory of the cycles in soil formation on the Riverine Plain is not well supported by his own investigations.

Butler's papers had an impressive impact on Australian pedologists and his principles have been nicely applied by others. Churchward (1961, 1963*a*-*c*) in the same Riverine Plain region followed with an elegant study of the ground surfaces in the Swan Hill district, Victoria, and showed their practical significance for irrigation. Later van Dijk (1959) for the Canberra, A.C.T., district and Walker (1963*a*,*b*) for the South Coast of New South Wales carried the ground surface principle into steeply dissected upland country.

Pedology of Laterite Formations

Since the original description of laterite in 1807, geologists had periodically discussed its nature and origin as part of the regolith. It was generally thought of as a product of weathering of rocks and not due to pedological process. In Australia its occurrence was recognized by geologists as both extensive and characteristic and associated especially with areas of ancient peneplanation. Prescott took up the theory of laterite formation put forward by Campbell in 1917 that it was the result of precipitation of ferric hydroxide in a zone subject to a fluctuating ground-water table. This was set out with some detail, emphasizing its occurrence on truncated old peneplain surfaces (Prescott 1931).* Although laterite may arise by alteration of rocks, the general situation in Australia of its pedological origin as a B horizon of a heavily leached soil has been accepted ever since Prescott's first publication. Whitehouse (1940) also agreed that the typical laterite in Queensland is the exposed remnant of a fossil B horizon of illuviated

*For a full review of theories on laterite and associated soils see Prescott and Pendleton (1952).

iron, concentrated at the approximate upper level of seasonally fluctuating ground water. His most interesting conclusion was that the period of major lateritization in Australia was late Tertiary and this has been generally supported.

Stephens (1946) contributed a very useful principle on the catenary array of soils derived from ancient lateritized surfaces by dissection. Briefly this is the idea of pedogenesis on a bevelled slope cut out by stream dissection of such surfaces, thereby exposing underlying deeply weathered horizons. Proceeding down slope from the lateritic capping there has been produced a succession of variously podzolized soils derived from further weathering of the gravelly or massive laterite, from the mottled zone beneath it, from the pallid zone deeper again, and finally from the exposed and unlateritized country rock. The variations are obvious and are complicated by derivation of soils from more than one horizon and by colluviation. These lateritic derivatives occur commonly as podzolic soils and the explanation of character and origin is simple and useful to surveyors both in field research and in fertility studies.

Basic research into lateritic formations was taken up 10 years later by Mulcahy and co-workers (Mulcahy 1960; Mulcahy and Hingston 1961) in Western Australia. Mulcahy's work was significant in combining pedological and geomorphological approaches and the definition of ground surfaces for the study. He developed new concepts on the history of the breaking down of the laterite and demonstrated a chronological series of surfaces of lateritic character descending from the ancient Tertiary peneplain. Arising from this is his hypothesis correlating the extensive sand plain areas of Western Australia with the coarse deposits transported, and possibly several times reworked, from the progressive breakdown of the old laterite surface. Stephens (1958) has postulated some continuance of lateritization into the Pleistocene and Mulcahy (*loc. cit.*) showed this more precisely. Bettenay (1961) carried Mulcahy's thesis eastward into a drier zone, where shallower and less massive laterite once formed. The origin and sequence of the soils investigated leading finally to the formation of the lateritic sandplain provide a basis for understanding not only the complex pedological pattern of important areas of the Western Australian wheat belt but the problems of land use also.

Arid Zone Soils

A small group of pedologists has lived with the arid environment in Australia sufficiently to begin to sketch in the interesting character of the desert landscape with its modified relics of ancient surfaces. It has been emphasized not only by pedologists but by botanists (Eardley 1948) and geologists that it is no ordinary desert formation and is unlike its counterparts elsewhere in the world. Pedologists have also found many unique features about it.

On the other hand it is only in the last 10 years that geologists have intensively studied the arid areas in the exploration for oil and minerals and have improved their accessibility. Some botanists have now moved through them for taxonomic and ecological reasons. As far as soil survey is concerned, dry inland Australia, at our present state of knowledge, is not a profitable field and this is not obviously likely to change.

Soil surveys have been carried out over very large unit areas aggregating more than 350,000 sq miles in Western, South, and central Australia and New South Wales, and in addition over considerable areas in the peripheral semi-arid zone. These have given a basic picture of the soil from which the few pedologists concerned have built individual concepts of the nature and origin of the formations.

The earliest worker was Crocker (1941) as a member of a team studying the character of the Simpson Desert in north-eastern South Australia. His description of the soils and ecology was the first detailed record of the soils of the dune and corridor landscape of the desert and its probable relation to the ancient laterite surface from south-western Queensland as a base layer on which the dune systems had been built.

But the more thorough and wide-ranging investigations were carried out by Jessup between about 1948 and 1960. His initial study was a survey of a large section of the north-west of South Australia (Jessup 1951). Later he covered a considerable zone in the arid parts of western New South Wales and south-western Queensland. From these surveys he discussed the origins of the landscape, soil occurrence, and genesis. This was particularly valuable work in a practical way also, in providing information on the soils and ecology of an arid region beyond the 8-inch rainfall line which was fully occupied but very sparsely used.

The soils as described by Jessup (1960*a-d*) are of widely different character and age and are deeper and have more profile differentiation than those of most other arid areas in the world. Wind and water erosion have been the moulding forces but probably due to finer and compacter soils and more protective surface cover they are more stable than other desertic regions with their long history of nomadic use and exploitation. There is a great mixture of soils, as relic and more recent formations dating from mid Tertiary to early Recent times, part wind-laid, part water-laid, and part of dual origin. The soils range from semi-lacustrine (grey soils of heavy texture) to lateritic soils and derivatives, to highly calcareous mallisols and desert soils, to solonetzic types, to acid red earths, all with a general eastward progression towards less calcareous and more acid soils. All these soils are distributed over an ancient land surface of marked relief and on a considerable part of which lateritic formations once existed. On these latter and their truncated remnants have developed silcrete layers concerning which so much discussion has arisen in recent years. Pedological research of this kind should be properly recognized. Whether Jessup's theories on the origin of stony tableland soils, of gypseous deposits and alunite seams are correct or not, is secondary to the amount of data presented and sought with considerable hardship in the field and we should be grateful he has been creatively positive in his interpretation.

Jackson (1958, 1962) made contributions more by way of enlightened soil survey and soil classification than pedological study but these have a considerable value in the thoroughness of observation and record. They are the basis on which the pedology of this arid portion of central Australia can best be studied. In particular he carried out an interesting and comparatively thorough survey of 18,000 sq miles surrounding Alice Springs. It has to be appreciated that the very nature of the environment, the restricted accessibility, the difficulty of deep examination of dry and very hard soils, called for considerable effort and skill in interpretation of observations. He showed the importance of climate and parent material, suggested a chronology and genesis for the soils, and pointed out the great lack of knowledge of the effects of leaching by the erratic rainfall under various forms of vegetative cover. This was an enlightened, pioneering, pedological study and survey.

Litchfield (1962) carried soil surveys in reconnaissance over wide areas of central and Western Australia, extending our information on the desert soils. Following a survey in the Wiluna district, Western Australia, Litchfield and Mabbutt (1962) added a short confirmatory page to the story of the acid hardpan soils previously described by Teakle (1936). Teakle had concluded that the extremely dense impenetrable hardpan at shallow depth was due to waterlogging leading to the solution and re-deposition of cementing agents, principally silica. These unique soils are another facet of the problems of Australian arid soils.

Desert work in soils is arduous and has none of the attraction of developing into applied research for greater agricultural production. Few face it for the long periods necessary to absorb the environment and to begin to interpret the pedology. We should acknowledge fully the debt to those who have literally toiled to give the present picture of the soils of arid Australia. It is a worthy contribution to world knowledge of arid regions rather than for particular national advantage.

Laboratory Techniques Complementary to Field Pedology

Field pedologists have always had to rely on their acuteness of observation and interpretation in studying profile morphology. Two new ideas have been developed by Australian research workers which seem to offer the kind of assistance the pedologists have sought. The value and significance to field pedology of all laboratory research are not discussed here. The two investigations to be mentioned are the studies of soil fabric and structure initiated by Brewer and the interpretation of homo- and heterogeneity of soil layers by Oertel.

Brewer and Sleeman's work (e.g. Sleeman 1963) on thin section microscopy of soils revealed the *in situ* arrangement of peds, particles, voids, concretions, and illuvial metallic concentrations, and made possible the interpretation of these in terms of pedogenesis. This technique has opened a vista of potential investigation of the nature and development of soil horizons and enabled examination of them comparatively. Brewer's (1964) textbook, which followed a series of papers on the technique by Brewer and Sleeman, was the summarized exposition of the methods employed for these studies and a full descriptive system of micromorphology.

Oertel's statistical study of trace metal constituents of soils by spectrography (e.g. Oertel 1961) seems to provide a new method of showing the relationship of soil horizons within and between profiles and to the respective parent material. His use of weighted means, trends, and measures of variableness of trace element profiles has considerable pedological significance.

Both Oertel's and Brewer's investigations are outstanding pieces of research and a comforting aid to the field pedologist who has long sought it.

Conclusion

This brief, necessarily selective summary of what are regarded as the principal avenues of field pedological research in Australia in the last 35 years makes no claim to comprehensiveness or to mention many other useful individual contributions. Looking back over these subjects, all of which are still active in some degree, there seems to have been for each an initiation by a key worker first striking a note, which echoed through the research of those following, who in turn amplified, added to, and criticized the original theses. Each attacked the problems in an individual way, some by perceptive imagination, some by logical research. The researches, although often backed by laboratory study, were really much more the products of pedological reasoning through field observation. It is also worth noting that most of the hypotheses arose from a basis created by soil surveys of one kind or another. In conclusion, the classic paper of Prescott's "Soils of Australia" (1931) should not be forgotten as the original inspiration, directly or indirectly, of much that followed.

VIII. THE FORWARD VIEW OF SOIL SURVEY

In concluding the historical review of pedological surveys in Australia it is apparent that most pedologists in this field of work have reached a state of fluid thinking, apparently not paralleled in other countries. The United States, Canada, Britain, New Zealand, Russia, and F.A.O., for example, are all proceeding with soil surveys of set pattern and more or less conventional type. Pedologists in Australia have seriously questioned the value of the old type of survey, whether it used soil types or great soil groups, but none are saying that the past work has failed to give a vast mass of data on the field occurrence and characteristics of our soils. What they are saying now is, Can relevant soil information be got more quickly and more soundly and with better results for the land user?, and it is on this theme the thinking is most active. The prime aim of the soil survey should be to provide the basis for correct land use for maximum production. The soil may only have an ultimate significance of, say, 25% in the end agronomic result, but it is the basis from which other investigations proceed, however inadequately this has been recognized in the past. After all, once we pass from a broad land resource survey (in which the soil is often a minor factor), all soil mapping is done for better use of land - for any agricultural purpose, for irrigation, for forestry, for engineering requirements, for national objectives such as conservation. Therefore it must yield a result in practical terms and the units used in mapping must have an applied value.

However, the more the subject is examined, the clearer becomes the need to struggle with the problem of classification until a suitable system emerges. Soil *is* a vital, key factor in land utilization. The reason the old system worked and in places is still regarded as useful is because in Australia there is, outside irrigation areas, little of the pressure on land that there is in more highly and intensively developed countries. Most of our land use is extensive and employs simple farming systems. The new areas rapidly developing in Western Australia and Queensland are for broad area grazing and mono-cropping agriculture. There is no pressure on use, no competition of uses, so the requirements of soil classification are not complicated. In the regions with a long history of settlement the problems are not so much changed land use as questions of fertility and soil loss.

There are some important questions to be asked. It is essential to analyse the present situation because we never know when soil field studies may be called for. We assume rightly that any practical problem requiring laboratory study should have a field background which takes the form of some kind of soil survey. If the situation demanding field opinion arose again urgently anywhere in Australia, as it did in the post-war settlement boom, should we do the same kind of survey as was done then? (and would it be as good as modern techniques justify?) If not, what kind?

But it seems once areas reach a certain maturity of agricultural development with an accumulation of practical knowledge of the soils, the basis of any survey has to shift and therefore needs to be reviewed. Anyone can make a catalogue of known facts about soils but that is scarcely a good soil survey. What is a possible new basis, particularly having in mind soil productivity? Then, considering the wide range of conditions over Australia and the variable extent of development, we should ask is there a common survey approach to be applied whether to support fertility studies in Tasmania, light land settlement in Western Australia, cattle-grazing in the Queensland brigalow belt, or new land use systems in old farmed areas of the New South Wales wheat belt. One approach could be applied, of course, but is that correct? We should ask also if the map and classification meet the requirements of the farm adviser.

Finally, since crops vary considerably in adaptability to soils conditions, some being restricted, should an attempt be made to define any limiting soil criteria, e.g. for a pine tree, a clover, flax, or cotton plant, and to decide the optimum soil conditions? We should begin on the old land to extract maximum productivity out of the best soils in consideration of both normal rainfall and subnormal years. Therefore the pF range over the seasonally wetted profile becomes of significance and relates back to the question of crop adaptability referred to above.

The following analysis endeavours to set out ideas and conclusions connected with soil and land mapping as it may develop in the future in Australia. One thing which has come to the fore is that the problem will be solved by the pedologist, not the users of soil maps, who in the great majority of cases have no concrete ideas often even of what they expect of a soil map, or are in an uncritical state of faith about them. The pedologist has to assume the role of integrator of crop-soil relations and of land use values. The latter touch sooner or later on the economic aspect, which, with the social and political sides, are not in his province as a scientist, though they have played a considerable part in past development.

Future of Soil Survey

The first question is, should we do soil surveys? There is no support among pedologists generally that a scheme of national soil survey should be undertaken, nor that a coordinated specialist federal body should be organized for this purpose. The national surveys in U.S.A., Canada, England, Scotland, and New Zealand, with their objective of mapping the whole country, or at least the parts agriculturally usable, are not seen as necessary in Australia. CSIRO has in the past been the federal surveying agency and coordinator of field data. Within the State bodies there is no enthusiasm for attempting a complete cover of their whole area and this not only because of lack of personnel. The general opinion is that surveys should only be undertaken as required for immediate use or to provide part or all of the answer to a problem. They become then matters of positive demand. Of course it may be nice to have complete soil surveys in detail of all arable Australia but there is a principle to be followed in not attempting to amass data which have little or no use in foreseeable time. There is also a great shortage of competent soil surveyors* and little desire among scientific workers at any level to make soil field work a career. We should also be clear that few of the users of soil survey data, who also include agronomists and fertility chemists, have specially sought or made the best use of it. Conservationists and irrigationists have been the most aware of the value of surveys and are the most active in seeking it now.

*Inquiries have been made on the training of soil surveyors and research field pedologists at institutions around Australia. The University Departments of Agriculture have small interest, although a move to give some training at post-graduate level is now current in Adelaide. It may be asked if agriculture or geology or geography would be the best training ground for surveyors or research pedologists. It is largely a matter of which discipline is imposed on the other. Two-thirds of the pedologists in the CSIRO Division of Soils were basically trained in agriculture, and possibly an even greater proportion among State workers. While soil surveyors for routine surveys can be trained readily enough, research pedologists are a disappearing race. They cannot be produced any more than, say, a research chemist without proper fundamental training and developed skills.

It is considered this is a serious problem, since active research in field pedology is basic not only to soil surveys in defining principles of soil occurrence but to all other disciplines in soil science and to pedogenetic studies. This research is also very valuable to geologists in the study of the Quaternary period, especially with the rise of their interest in the stratigraphy of surface sedimentary deposits. It is essential that the presently active body of research field pedologists in Australia, which probably does not exceed 10, be preserved at least without diminution and that consideration be given to their successors. It is significant that not one university in Australia possesses a fully competent field pedologist on its research or teaching staff.

We should not just go on drawing soil maps irrespective of immediate need. The survey must have a clear object. Excellent examples of these have been quoted in Section V; land development with closer settlement is another obvious case when survey becomes a definite requirement. It is not thought that progress in soil surveys will accelerate. The older farmed land is not likely to be further examined unless there are drastic changes in land use. New land for closer settlement will demand a survey of some kind as is operative in Queensland and Western Australia.

It is concluded that a national soil survey is not a demand but that surveys with clear objectives should proceed in a suitable form.

Form of Survey

The second question naturally follows: what should be the form of the soil survey? The land survey and the soil survey have to be distinguished, although each is partly inclusive of the other. Most mapping of land involves an array of environmental features controlling the nature and use of the soil. The difference between it and soil survey is that environment and associated forces dominate, the soil factor being significant in a variable, sometimes low degree. In soil mapping the soil *per se* dominates, and the environment contributes to the definition and interpretation of the mapping unit.

Land Surveys.-Land system surveys have their rightful place in dealing rapidly with overall resources in regions of low agricultural development or difficult of access. At the broad level the land system mapping brings together an array of useful data, including soils, as a first approximation to the potential usefulness of undeveloped areas. Its hidden complexity, arising from the need for simplification at the scale of mapping, has to be disentangled for the user, where more intensive use is practicable, in the form of land, or soil, maps with few parameters. These units are considered to be no longer land systems whatever they may have been called.

In more recent times they have been applied in a kind of refined form (micro-land systems) on smaller areas and to areas being planned for greater agricultural development in producing land capability maps via soil, parent material, and topography as an exercise in multi-factorial mapping.

It is concluded that the land system mapping in its place, particularly where access is restricted and development at a low level, offers the best reconnaissance approach to understanding land capability. It is not thought the land system in developed country has any special merit in itself and it is debatable whether the land unit has any advantage over the modern soil association. Land surveys are not a substitute for soil surveys if we are concerned with fertility problems or seeking maximum production per acre.

The Use of Great Soil Groups and Subgroups.-Ever since Prescott applied the great soil group to mapping continental Australia in 1931, many others have set about devising new groups and constructing maps of lesser areas. The continental assessment, mapped in this way for convenience at say 1:5,000,000, is of no real value for agricultural development. In general the same applies to some regional surveys employing great soil groups which cannot be applied practically, though, having greater map detail, they may be slightly more useful. We must always keep in mind the breadth of constitution of the great soil groups and the latitude taken by observers in classification of soils as "the nearest group". The more one works with great soil groups, apparently the more infrequent seems to be the ideal, modal profile in nature. It seems clear that great soil group associations alone do not yield a very useful picture, interpretable practically in terms of land capability. The mapping only tells us what general kinds of soils may be expected, although there is all the difference in the world between, say, stony minimal to deep maximal yellow podzolic soils on the same, quite apart from different, parent materials.

A development of surveying by great soil groups introduces topography and lithology. For example Nicolls (1958) and others in Tasmania speak of black soils on basalt and on dolerite, podzolic soils on dolerite and on mudstones. In some parts of Australia this has more specific application, although before the soils are mapped it is necessary to have available or to work out the geology of the area with some detail in order to use the lithology as a base for superposition of soil units. If this is combined with topography it is possible to produce a superior kind of great soil group map by introducing suitable subgroups.* A map on this basis might be sufficient description of the soils for simple land use patterns. It might serve for soil fertility correlations beginning with land little changed from its original state by management practices. It might be a basis for land capability classification developed with topographic assessment from aerial photographs. It will not apply to old farming country and it is comparatively slow in the absence of good geological base maps. It needs, of course, to be accompanied by skilled interpretation at the individual farm level where, for example, texture and depth of A horizons of duplex soils, depth of solum as potential rooting zone, can be examined for relation to land use. The type of survey and soil classification employed may vary to suit conditions in different parts of Australia. The climatic and farming systems govern the approach as may be seen in the following cases.

In subcoastal and central Queensland, soil mapping in recent years has employed soil associations based on great soil groups, lithology, and land form and defined the types described according to the Northcote key. A recent publication by Isbell (1966) is a good example. It deals with typical cattle fattening and breeding lands in central Queensland on which sown pastures and fodder crops are becoming increasingly important.** For

*For example one soil survey in Queensland (unpublished) uses mapping units like the following:

Hilly shale and phyllite country: shallow gravelly loams and gravelly loams with thin clay subsoils - lithosols, podzolic soils, and solodic soils.

**An example of a unit used by Isbell (1966) is

Gatton Vale Association: Solodized solonetz with solodic soils and various podzolic soils. Broadly undulating slightly elevated lands. Parent material - slightly feldspathic sandstones of Upper Brown Coal measures. Principal profile forms - dominant Dy3.33, Dy2.43, Db1.43; associated soils Dr2.31, Dy5.33.

general purposes this seems a sound working base for application to these specific conditions. It is possible to superpose land capability classes, controlled by such features as slope, erodability, natural fertility, hard-setting surfaces, which may simplify the pattern for actual land use.

It is concluded that where further details as to boundaries of individual soils are not required, i.e. when the land use is simple and broad, the type of survey described above is adequate. It sould thus apply as a principal step to the very great part of Queensland and north Australia potentially suited to arable agriculture, but now at a low level of development. It is not a system for old farming land of south-eastern Australia, or for any lands damaged by management practice. There is a measure of subjectiveness in this broad unit mapping which should not be pushed too far, e.g. for soil fertility correlations. In any case nutrient deficiencies have to be determined by analysis and pot experiment to prove the subgroup units are reliable. The use of the technique is governed by the object of the survey and the resources available for its conduct.

By contrast we should consider the case of breaking up virgin light lands in Western Australia with a relatively low rainfall, which has to be conserved, and in areas where a salinity problem occurs. The parameters are quite different to those of humid Queensland. Depth of coarse-textured surface, gravelliness, calcareousness, slope, seepage, salt equilibrium in the profile, are the kind of things controlling mapping units. Since these areas are simply for cereal-cropping with sheep-grazing, the mapping can be in direct land capability units with a specific set of limitations. As they are all low-fertility soils differences in nutrient deficiency are much less significant than rooting depths and seasonal moisture retention. The keys to development of such lands have been or should be established by long periods of investigation at appropriate experimental farms.

It is concluded that for expansion of agriculture on light lands to new limits in Western Australia a simplified land classification system based on the results of investigation at experimental centres is adequate, even if it appears crude by comparison with some soil survey approaches. It is considered its application to other parts of Australia is problematical. It also does not serve the higher-rainfall and old farmed land in Western Australia.

The high-rainfall belt of southern and eastern Australia poses different problems. The State Departments in Victoria and South Australia (see Section V) have devised their own mapping plans, neither of which is thought the new substitute for the old soil survey.

Factors in Modern Soil Surveying

Modern soil surveys applied to arable lands involve a technique of classification and a mapping of units with similar or equivalent significant features, generally viewed in relation to agricultural production. We have seen in the broad sense this may reasonably be met using great soil group subgroups with ancillary factors. What are the principles for the more specific surveys?

There are two aspects involved. One is the soil in relation to landforms, the other the soil profile in relation to plant growth.

Before a survey proceeds in detail the landscape and its derivation should be studied to provide a basic background. This does not prescribe that soils of similar character may not appear on two surfaces or that different soils may not appear on the one surface. The landform sets conditions of comparative uniformity subject to the influence of micro-environment and parent material. On this basis the principles of occurrence of soils - mode of origin, derivation of parent material, influences to which they are subject such as drainage, relation to past soils, comparative age - may be established. Butler's concept of ground surfaces (Section VII) as an expression of the soil-building process is useful. Other pedologists have used this with variations.

But in classifying the soil profile for mapping there is less agreement. There are the present-day exponents of the traditional soil type and it is quite possible a considerable proportion of working surveyors would, if put to it, use the same unit perhaps with more flexibility. Secondly, there is the Northcote key (Section V), applicable to a certain degree but admittedly lacking in precision to be useful for closer mapping at the farm level. As indicated earlier it would need to be extended, probably, two steps further. Thirdly, there are the pedologists looking at correlation of soil and plant growth with a view to defining parameters applicable to specific crops.

One of the failings of the survey systems, great soil groups, or soil types, is the difficulty in achieving agreement between workers acting independently, on definition of mapping units and hence soil boundaries. The United States Soil Survey endeavours to overcome this by an overriding decision of high-level coordinators for each unit mapped. The Australian soil survey has never enforced this. Such freedom has its good points but it also creates problems. Clearly a more logical, less subjective system would be advantageous.

There are some principal keys to soil evaluation. The prime one is the "moisture physics" of the profile coupled with "root physics" and these usually go together. The key to dry-land agriculture in Australia is water. In the long view over most of the continent there is no such thing as too much water from rainfall. So anything which affects the hydrology of the soil profile is significant in soil mapping. External and internal hydrology, absorptiveness of the surface layer, have to be emphasized both under native vegetation or under imposed land use, whether arable, grazing, or afforestation. A soil which disperses and crusts at the surface, soil which potentially erodes by sheet, gully, or tunnel, soil with slowly permeable clays, soil with cracking clays, soils with undamageable structure, soils allowing free vertical movement or lateral seepage of water, waterlogging soils, soil with a narrow range of moisture allowing cultivation - all these are important separating features before any consideration is given to fertility.

In practical mapping the soil-water regime must be kept dominantly in mind both for individual horizons and for the whole rooting zone. Penetrability of soil layers by roots is normally correlatable with the moisture profile as affected by aeration, permeability, gross water retention, net amount of available water over the pF range, for the constituent layers. The thickness of the A horizon is important in relation to surface development of plant roots and moisture supply and the depth of solum in relation to overall moisture retention.

So long as the "moisture-soil" principle is accepted attempts may be made to use it in conjunction with either of the three approaches mentioned above in this chapter. It is probable the idea was used in the traditional soil type but in a vaguer way. Giving it dominance would help to define a better practical unit. The Northcote key, although much criticized, did make use of profile features relevant to the case in setting up principal profile forms. For example, hard-setting surfaces, cracking clays, hardpans, organic content, all affect soil moisture and rooting from the plant side. If the key were to be extended the parameters used would have to be seen in relation to those given lower priority with which covariance should be aimed at.

It may be argued that any system aiming at separating soil units on "moisture" criteria becomes increasingly subjective. It is difficult to see how any survey procedure for classification in the field can be otherwise if land use is considered. Guesses on the spot, for example, of moisture content for the pF range of many types of soils are of doubtful accuracy. The integrating computer for assessing the value of soil features has to be in the surveyor's head unless distinguishing parameters are reduced to very simple terms which would only occasionally be possible. Otherwise the interpretation of the profile as a medium for specific plant growth is a matter of judgment aided by any easily managed and rapid field tests.

What has been said for dry-land agriculture applies even more strictly to irrigation. A plant may, of course, grow equally well in two apparently distinct soil types because a certain common property of the soil profiles is a key factor. It is not thought root ecology in relation to the physical profile and the absorption of available water has been studied enough. This cannot be dealt with comfortably in a glasshouse and is an unattractive and frustrating field labour.

It would be better if the requirements of the profile horizons could be defined for specific crops, but unfortunately this is not too well known. We should like to know, for example, the optimum physical characteristics of the soil profile for growing cotton or tobacco or peaches or citrus on different stocks so that given a climatic range and irrigation we could look for suitable soils. A little of this has been attempted (van Wijk 1962; Cockroft, Bakker, and Wallbrink 1962).

Perhaps, and especially if we knew more of these plant-soil relations, the answer to classification for surveys under irrigation is not one map but a series of maps from which by superposition a combination of features might produce a soil unit with a specific use value. We might map separately, for example, the nature of depth to D horizons, thickness and texture class of surface horizon, depth to a layer with high content of calcium carbonate, texture and structure of B horizons interpretable in terms of water permeation and root penetrability. Out of these data would come a clear view of possibilities of waterlogging, drainability in terms of depth and spacing of tile drains, removal of soluble salts from the root zone, all of which link with specific crops.

It has to be remembered that storage and diversion sites on controlled streams may be limited and the conservation of water may necessitate use of areas with soils of less favourable character. In such cases the crop adaptability is important. The summation of the features discussed, fitted to a landscape of acceptable topography and agriculturally workable soils, affords a basis for soil classification to meet requirements. It is felt that too little is known of many soil features in making meaningful maps of new irrigation areas - just as too little is known about crop growth and root extent and distribution in different kinds of profiles under different moisture regimes. We might pertinently add in the light of present trends in agriculture an argument for research to obtain the maximum yield from the minimum area with the best economy, especially, but not only, with irrigation available. So far very little, if any, soil research has been done on quality of product. The old argument we meet so often that management is the dominant factor in production is a tacit acknowledgment that the soil in itself is a significant variable. Soil survey must not be separated from the agricultural relationship of its mapping units.

Conclusion

In concluding this review it is essential to recognize that all soil mapping, other than for pedological research, is for the land user; it must be as informative and sound as possible and cover use potential and hazards. Perfect surveys would only be practicable if we knew all essential things about the soil itself and their relation to land use, but earth science is far from being understood like that. A soil survey, by itself, has no value. A soil type has to mean something practically. In the past, soil surveys have been thought of as so basic that they were independent of land use. Differences were seen by the pedologist which were not reflected in foreseeable practice. We may have made the mistake of approaching survey problems "scientifically" and found the results did not reconcile with practical aspects due perhaps to using wrong distinguishing features. We have to see correlation between profile character and crop response. If we are thinking of soil fertility there may be significant things inherent in the soil profile or parent material perhaps not obvious on the surface and unrelated to vegetation or landform. Mapping must not be left to intuition although the surveyor will always have to think subjectively.

The soil survey should not aim to be too purely "soil". It set out to supplant land classification by the pioneers and has in some quarters ended by joining it in evaluating land capability classes. But the latter are not seen as necessarily the best expression of soil. The great need is for more and more basic data which may be correlated on a statistical basis. For example one problem which only statistical treatment can solve is the permissible range in a property before it becomes limiting to plant growth of a given type. For many soil properties the range may be so wide that precise definition is not worth attempting for a particular soil.

A statistical approach* may begin to take the subjectiveness out of soil survey. If we cared to make maps each with one variable, a soil or land or vegetation attribute, and bring them together as an assemblage and integrate them we might end with a near-perfect composite. But to attempt to combine a large number of parameters, say 10 or 20, in making a soil map merely results in either a very complicated map with too many units or, if simplified by grouping the units, produces heterogeneous complexes of questionable value to the land user. The greater the number of independent parameters the worse the result becomes. In any case it is quite impractical economically and even so, one would always have to watch for results weighted through personal emphasis by the recorder. There are limits on mathematical analysis of soil classification. In the field subjective soil classification at some level is inevitable as long as soils refuse to be neatly pigeonholed and exhibit all kinds of gradational variations over short distances.

The objective of the soil survey colours the approach, be it development of new land in broad acres, irrigation, problems in fertility, land resources, engineering values, or other purposes. No one method is justifiable for all. In some cases of old farm land possibly no economic, useful survey is practicable, due to disequilibrium of the natural soil, but generally a working survey can be made, particularly if the number of factors considered significant for land use is comparatively small.

The past 40 years have seen an immense accumulation of data from soil surveys, of tremendous value to land development and farming and basis to much research in agronomy and soil productivity. The very recent trend to think in terms of storing, in a readily accessible form, data from detailed observation during surveys, so that at any future time any features may be extracted for interpretation or for direct application, will be of great value in making sound soil maps of even greater usefulness. We are now at a stage when land capability is being worked out through soil survey on new arable lands in Queensland, Western Australia, and north Australia as a first step towards development. If we wish to study the soil as a fractional contributor to crop yield it is essential for the soil scientist to play a much greater part than in the past in seeing the reflection of his classification and mapping in the response of plants.

We have not finished with maps, but must not map for mapping's sake. Survey has very largely paused in the southern temperate areas. However, as soon as pressure on land use becomes great enough and the urge to maximum productivity on the better-rainfall lands becomes strong, the application of soil survey there in a new form should come again. The form will be for the pedologists to devise. It will be as well to have them for the task and ensure that they do not disappear in the meantime.

*Recently, studies have been made by statistical correlation of soil properties with a view to defining "soil types" with specific characters (Russell and Moore 1967). This mathematical classification based on laboratory data is interesting to the pedologist, especially as a means of confirming field observation. No attempt has been made to discuss the question in this review as it will need time to bring it into perspective.

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